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Heap Leach Technology and
Potential Effects in the Black Hills

Engineering-Science, Inc., Denver, CO

Prepared for

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999 18th STREET, SUITE 1300
DENVER, COLORADO 80202**

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PREPARED BY

ENGINEERING-SCIENCE

DESIGN • RESEARCH • PLANNING

**1100 STOUT STREET, SUITE 1100
DENVER, COLORADO 80204**

WITH ASSISTANCE FROM

HAMMER, SILER, GEORGE ASSOCIATES

**1638 PENNSYLVANIA STREET
DENVER, COLORADO 80203**

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Prepared By

Engineering-Science
Design-Research-Planning
1100 Stout Street, Suite 1100
Denver, Colorado 80204

With Assistance From

Hammer, Siler, George Associates
1638 Pennsylvania Street
Denver, Colorado 80203

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ABSTRACT

Typical cyanide heap leach operations for precious metals recovery are described. A hypothetical facility was placed at three sites in the Black Hills of South Dakota to facilitate a discussion of environmental and socioeconomic impacts. Since a cyanide heap leach facility is a closed system, and would not, under ordinary operating conditions, discharge fluids to surface or ground water, impacts from a properly designed and operated project would not be a greater threat to environmental quality than industrial developments not using cyanide. Soils, vegetation, and wildlife habitat would be disturbed throughout the life of the project. Most of the adverse impacts to these resources would not continue beyond reclamation. Many safeguards against accidental release of cyanide-containing solutions are incorporated into mine designs. However, in the unlikely event of a spill or leak of cyanide-containing solution, toxic substances could be released to surface and ground waters. Most impacts would be short-term because of dilution and cyanide attenuation. Mine development would have beneficial effects on the economic base but could adversely effect recreation and seasonal housing. Many impacts could be mitigated by implementing best management practices and establishing a cooperative environment between mining officials, local officials, and affected residents.

PROJECT SUMMARY

The cyanide heap leaching process is an effective low-cost method of recovering precious metals from suitable ores that are uneconomic to process by other methods. Although most operations of cyanide heap leach facilities have no discharges, certain aspects such as sediment control may require discharge to surface water. As a result, the U.S. Environmental Protection Agency (EPA) expects to receive a number of discharge permit applications for gold mine heap leach facilities. This study, prepared in response to that need, characterizes the potential environmental and socioeconomic effects of open pit gold mining and cyanide heap leach processing in the Black Hills of South Dakota.

Typical Heap Leach Operation

Cyanide heap leach facilities consist of an open pit mine, waste rock dump, low grade stockpile (optional), leach pad, process ponds, and process plant. The life of a typical heap leach facility ranges from 5 to 20 years with typical production rates from 3,600 to 11,000 metric tons (4,000 to 12,000 short tons) per day. Mining to obtain the ore for the leaching facilities is similar to most other open pit operations and includes drilling and blasting followed by excavation and haulage. Material that is mined is separated into ore, low grade, or waste rock and is hauled to the leaching facility, low grade stockpile, or waste rock pile, respectively. Ore may be crushed, agglomerated with cement or lime, or used untreated as run-of-mine ore.

The leach pad is constructed of materials such as clay, plastic sheeting, and/or asphalt-type materials which provide an impervious barrier to the process solution. Leak detection systems are constructed below the heap pad at some operations. The heap is formed by placing the ore on the leach pad and preparing it for leaching by methods such as grading or ripping. Process solution containing cyanide at concentrations ranging from 100 to 1000 mg/l is then sprayed on the heap from sprinklers. Some operations re-use heap pads so that

ore is leached, rinsed, drained, and replaced with unleached ore. Other facilities use permanent pads where the ore is leached until extraction becomes uneconomical. As the cyanide solution drains through the ore it dissolves gold and silver from the ore. The process solution which contains the metal values, called the pregnant solution, is stored in the pregnant pond. Two types of process units, carbon column or zinc precipitation, can be used to remove gold and silver from the pregnant solution. After the values are removed, the barren solution is returned to the barren pond and pumped back to the heap for more leaching. Emergency overflow ponds may be installed to prevent spills resulting from severe storms. Ponds are lined with impervious materials, including clay and/or synthetic liners. Monitoring programs, including visual inspection and monitoring wells, can be used to provide an indication of leakage.

Rinsing with either fresh water or an alkaline chlorine solution is generally used to destroy residual cyanide prior to closing spent heaps. Barren solution and the rinsing solution from neutralization of the spent heaps are subject to cyanide destruction upon facility closure. The degree to which specific sites must be reclaimed varies by state.

Impact Evaluation

Three sites in the Spearfish Creek, Whitewood Creek, and Bear Butte Creek watersheds in the northern Black Hills of South Dakota were chosen to assess potential impacts. A hypothetical cyanide heap leach operation was designed, based on information available from the literature and mine visits, and imposed on an area of potentially mineable ore in each watershed so that environmental and socioeconomic impacts could be assessed. Environmental and socioeconomic resources for each watershed are summarized below.

Geology. Gold was discovered in the Black Hills of South Dakota more than a century ago and has been actively mined since then.

With the increase in gold prices, there is potential for economically extracting gold from low grade Tertiary replacement deposits using heap leaching technology.

Ground Water. Ground water resources, including springs and both shallow (alluvial) and deeper ground water aquifers, may be suitable for domestic and agricultural uses. Principal aquifers in the area are carbonate aquifers (Spearfish Creek and Bear Butte Creek watersheds) and sandstone aquifers (Whitewood Creek and Bear Butte Creek watersheds). Water quality of some wells exceeded EPA secondary drinking water criteria for manganese, iron, or sulfate and the EPA Maximum Contaminant Level for chromium.

Surface Water. Surface water quality of the Spearfish and Bear Butte Creek drainages is relatively good, but the water quality of Whitewood Creek has exceeded EPA standards for some heavy metals and cyanide because of past mining activities. The water quality of Whitewood Creek, however, has recently improved. All three streams support a fishery. Water from Whitewood Creek is used for irrigation and mining. Spearfish Creek is used as a municipal water supply for the town of Spearfish. Surface water uses of Bear Butte Creek are made primarily downstream from the Black Hills.

Soils. Soils are predominantly loamy and moderately deep. They support land uses such as forest, wildlife habitat, rangeland, and recreation.

Vegetation. Although ponderosa pine forest covers most of the northern Black Hills, grasslands and riparian vegetation exist in lower slope and valley bottoms. No candidate or Federally-listed threatened or endangered plant species are known to occur in the three watersheds.

Wildlife. Wildlife resources include elk, deer, small mammals, raptors, and game birds and songbirds. Critical winter habitat for elk and deer occurs in all three watersheds. The potential exists for Federally-listed threatened or endangered species to use the study areas, but without further studies it is not possible to quantify species occurrence.

Aquatic Life. An important recreational fishery exists in the northern Black Hills. With the recent improvement in water quality in Whitewood Creek, there has been an active effort to increase the productivity of the fishery.

Socioeconomics. The area relies heavily on mining and agricultural activities for its economic base. Diversification into recreation and tourism has recently occurred. Employment growth has slowed since the 1970 to 1980 period. Gold mining is the key influence in determining the current level and pattern of development in the area.

A hypothetical cyanide heap leach facility consisting of a mine pit, waste rock dump, crushing area, leach pad, process plant, pregnant pond, barren pond, neutralization pond, and overflow pond was described to facilitate the impact discussion. The operation would cover approximately 1,000 acres and would employ about 100 people throughout a 10-year mine life. Closure would consist of the neutralization of the spent ore heap, disposal of the process solution, and decommissioning and reclamation of all facilities. Reclamation involves disposal of waste material, dismantling of buildings and roads, decommissioning of heaps and ponds, grading, topsoiling, and revegetating so that the land is returned to beneficial use.

Effects of the construction and regular operations of the mine facility depend on the location of the facility, the areal extent of the disturbance, and the configuration of the mine facilities. Adverse effects on ground water supply may occur in conjunction with pumping drawdown from wells used for mine water. Negative impacts to surface water and to aquatic life may result from increased sedimentation,

which would occur primarily during the construction phase. The impacts from sedimentation may be insignificant if adequate sediment control structures are used. Impacts to soils and vegetation would be primarily a function of the area disturbed and the amount of post-mining reclamation. Wildlife would be affected by habitat losses and degradation and increases in wildlife-human confrontation. The significance of the effects depends on the species present, the amount of the habitat lost or degraded and its availability outside the impacted area, and the intensity of human encounters with wildlife.

Although socioeconomic effects are influenced by the distance of the operation from developed recreational areas and population centers, most impacts would be similar regardless of the location of the actual mining operation. Generally, there would be moderate, beneficial impacts on employment, income, and the economic base during the life of the project. This would be accompanied by positive but insignificant impacts in population and permanent housing in local towns. The need for additional services is expected to result in a negative but insignificant impact on local government budgets.

Local governments would bear almost all of the additional costs associated with required public services whereas public revenues generated by the mining operation would be shared by the State, county, and cities. These revenues would generally be spread over a broader geographic area than would the demands for services. The significance of impacts on recreation and seasonal homes is site specific and would be influenced by the specific location and characteristics of a mining operation. Cumulative impacts from additional mines should be considered.

The cyanide process is a closed system and will not discharge any fluids to surface or ground waters during normal operating procedures. For purposes of evaluating impacts, two types of accidental releases, a pregnant pond overflow and a pregnant pond leak, were analyzed for potential effects. In the analyses both accidental releases contained

cyanide at concentrations of approximately 200 mg/l as well as small amounts of several metals. An accidental release would be highly unlikely at a well operated and maintained cyanide leaching facility.

Cyanide is a very reactive and relatively short-lived contaminant. Several chemical and biological processes transform free cyanide into less toxic forms when it is released to the environment. Effects from a spill to surface water on aquatic life would be short-term and range from significant on a stream adjacent to the facility to insignificant in downstream reaches because of dilution and attenuation. Some direct wildlife mortality could occur during a spill if animals were to drink the spilled solution before dilution or degradation of the toxic components could occur. Impacts from a spill would be short-term and insignificant to soil and vegetation. In the case of a pond leak, impacts to ground water could be potentially significant if the water table is near the surface. The leak would have minimal effects on surface water and aquatic life unless the distance between the leak and the ground water discharge point to surface waters was small. Impacts from a leak on soils would be short-term and insignificant because potentially toxic solution constituents would be transformed to harmless or inert forms within the soil. Generally, no impacts to wildlife or vegetation would be expected from a leak.

Impacts from heap leach mining and processing can be mitigated by using various site-specific actions. By locating facilities such as ponds, plants, and pads which have potential for leaking on sites away from important aquifers and major streams, the extent of impacts to ground and surface waters and to aquatic life from accidental releases will be reduced. The areal extent of surface disturbance is the major factor affecting soils and vegetation. Minimizing surface disturbance and avoiding sensitive or unique areas can decrease potential impacts. In areas that are disturbed, site-specific reclamation measures can be developed and implemented. Impacts to wildlife result mainly from habitat destruction. Habitat disturbance can be minimized by avoiding

sensitive or unique areas. Mitigation of potential socioeconomic impacts can be accomplished by establishment of a cooperative working environment between mining companies, local officials, and affected residents.

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CHAPTER 1

INTRODUCTION

BACKGROUND

The cyanide heap leaching process is an important method for the recovery of gold and silver from low grade ores. The procedure offers a low cost, effective means of recovering precious metals from ores which are difficult or uneconomic to process by other methods. It has been applied both to freshly mined ore from low grade deposits and to the reprocessing of tailings left by earlier mining operations.

Gold was discovered in the Black Hills of South Dakota more than a century ago and has been actively mined since then. Most profitable ore bodies were exploited long ago and, after the ore played out, most mining operations became uneconomical and were shut down. However, with the increase in the price of gold, there has been a resurgence in mining and exploration. Cyanide heap leaching is the preferred technology for processing ore from revitalized mines when permitted by geologic and metallurgical conditions.

Section 402 of the Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977, requires the administrator of the U.S. Environmental Protection Agency (EPA) to issue permits for the discharge of pollutants to the waters of the United States. The issue of permits is conducted under the National Pollutant Discharge Elimination System (NPDES). Although most operations of a cyanide heap leach facility are closed systems, i.e., have no discharges, certain aspects such as sediment control may require discharge to surface water. As a result, EPA expects to receive a number of discharge permit applications for gold mine heap leach facilities. In order to better carry out its obligations under the Clean Water Act, the EPA contracted for this environmental study of the Black Hills to delineate the possible impacts of heap leach gold mining operations in the area.

SCOPE OF WORK AND APPROACH

The purpose of this study was to characterize the potential environmental and socioeconomic effects of heap leach gold mining in the Black Hills of South Dakota and to prepare a resource document for the EPA's use in reviewing and assessing proposed heap leach gold projects in the area. Three watersheds located in the northern Black Hills of South Dakota were chosen for study. These were the Spearfish Creek, Whitewood Creek, and Bear Butte Creek watersheds (Figure 1).

The Spearfish Creek watershed was the site of several historical mining operations. The Annie Creek Mine, Ltd., owned by Wharf Resources, is the only currently operating cyanide heap leach facility in the Black Hills. It is located in the Spearfish Creek watershed and is shown on Figure 2. Whitewood Creek has been substantially impacted by past mining activities. The reach downstream from Crook City to the confluence with the Belle Fourche River was listed as a Superfund site because of contamination by toxic substances in mine tailings. The Homestake Mine, which has operated along Whitewood Creek for over 100 years, is still active in this watershed (see Figure 2). The Bear Butte Creek watershed was also the site of historical mining operations, and several tailings piles still remain. Currently, however, there is no active mining.

Each of these watersheds contains additional ore which could be processed in a cyanide leaching facility. To determine possible impacts, a site was chosen within each watershed for placement of a hypothetical heap leach mining operation. Each of the selected sites was in an area of potentially mineable ore near the headwaters of the major drainage. The locations of the three sites are shown in Figure 2. In the Spearfish Creek watershed, the hypothetical mine site is located on Raspberry Gulch. The hypothetical mine site in the Whitewood Creek drainage is located on Yellow Creek. In the Bear Butte Creek watershed, it is located on Two Bit Creek.

**FIGURE 1
LOCATION MAP**

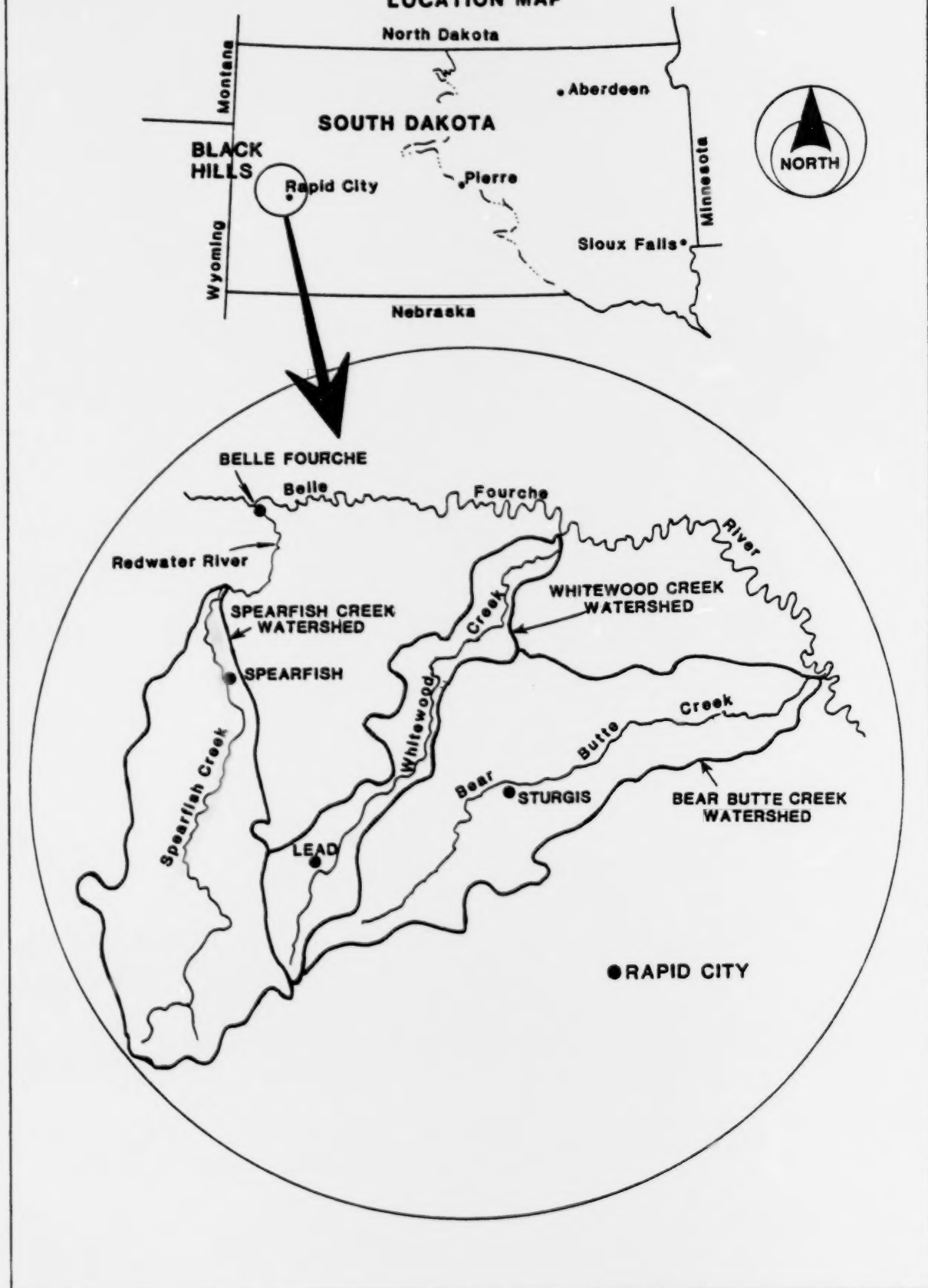
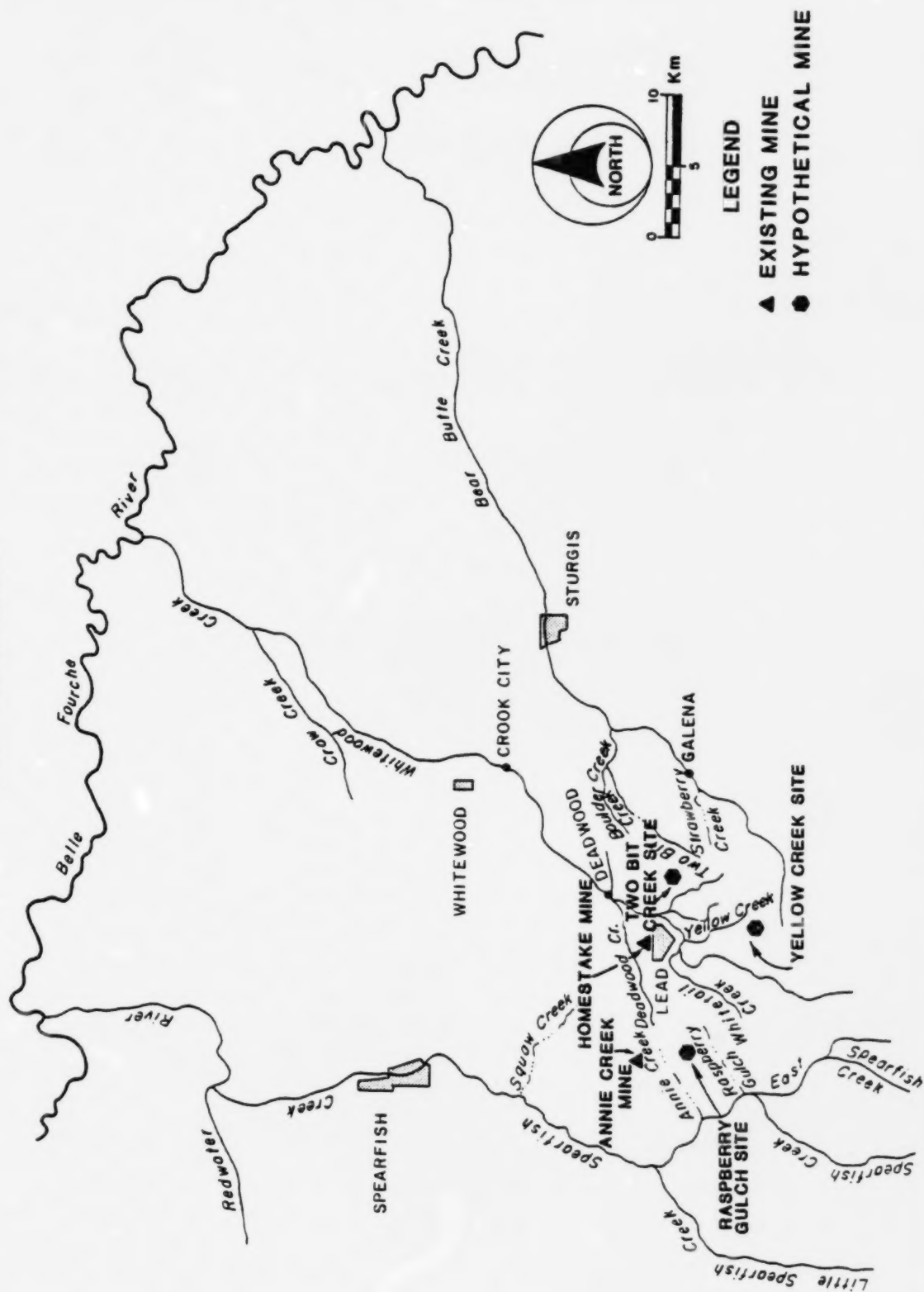


FIGURE 2
SITE LOCATIONS FOR HYPOTHETICAL
HEAP LEACH MINES



Baseline characteristics were developed for the vicinities of each mine site. A typical cyanide heap leach operation was then designed, based on information available from the literature and from tours of two operating heap leach mines. The typical heap leach mine was then "placed" in each watershed and potential impacts from each mine were determined.

A general discussion of gold mining and the cyanide heap leach process is presented in Chapter 2. Physical, biological, and socioeconomic data on the existing environment of the three chosen watersheds in the Black Hills are discussed in Chapter 3. Typical mine design and potential impacts from the construction and operation of the typical mine in each drainage, as well as for a hypothetical cyanide spill and leak, are discussed in Chapter 4. Mitigation options are outlined in Chapter 5. Appendix A contains a description of the two operating mines that were toured. Data from these mines and information in the literature were used to develop the typical mine design for this study. Information on the chemistry and toxicity of cyanide is discussed in detail in Appendices B and C, respectively. Appendix D contains data from actual cyanide releases from heap leach operations. This information was used to develop the hypothetical spill case in Chapter 4.

All descriptions and analyses in this report are based on information available from the scientific and technical literature, State and Federal agencies, and the mining companies. Although a site reconnaissance of the three watersheds was performed, no field data were collected.

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CHAPTER 2

HEAP LEACH GOLD MINING AND PROCESSING

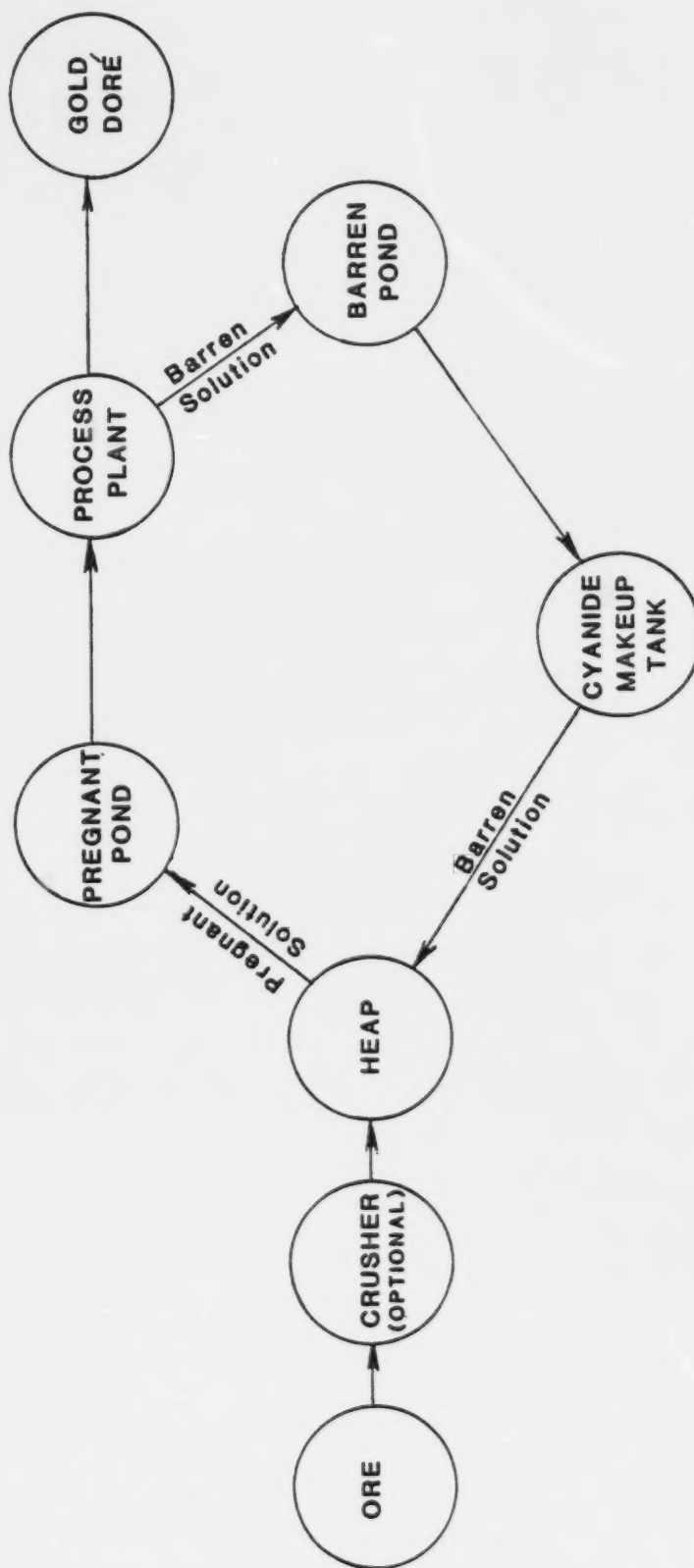
Heap leach mining and processing is an alternative to conventional mining and milling operations for recovery of precious metals from low grade ores. Open pit mining, the mining method used at most heap leaching operations, requires a near-surface gold and/or silver ore body in order to reduce waste-to-ore stripping ratios. Open pit mining is less costly than conventional underground mining methods. Heap leach processing involves spraying a cyanide solution on the ore which has been mined, crushed, and formed into a heap, to dissolve the metal values, collecting the solution containing the dissolved metals, and recovering the metals from solution. A schematic diagram of the leaching process is presented in Figure 3. Open pit mining and cyanide heap leaching has lower capital and operating costs, and reduced startup time, compared to milling operations. Ore can be economically leached at grades approximately an order of magnitude lower than those commonly milled. A disadvantage of heap leaching is that the metal recovery may not be as good as by conventional milling. Economic success of heap leaching depends on the ore location, ore preparation, solution presentation to the ore, solution collection, and the minimizing of solution loss prior to recovery. The steps involved in cyanide heap leach processing are discussed below. In addition, details of two operating heap leach mines are discussed in Appendix A. For a detailed discussion on cyanide chemistry, refer to Appendix B.

ORE TYPE AND PREPARATION

Ore Type

Important ore mineralogical and other aspects required for heap leaching are as follows:

FIGURE 3
FLOW CHART DIAGRAM OF
HEAP LEACH PROCESSING



- . The gold (Au) and silver (Ag) should be of very fine (micron range) size. Ores should be of the disseminated type. Coarse gold or silver does not leach at practical rates because of small surface area.
- . Low-grade ores can be economically treated by heap leaching but could not be by milling. Some heap leach operations are treating ores as low as 1 gram (0.03 troy ounces) of gold per metric ton (short ton) with cut off grades as low as 0.3 grams per metric ton (0.01 troy ounces per short ton).
- . Ores which have been weathered or are oxidized are amenable to leaching because gold has been liberated from the original sulfides. Ores containing an excess of cyanide consuming constituents such as iron and sulfide may not be suitable for leaching.
- . Ores which contain organic carbon will experience low recoveries because of the tendency for the carbon to adsorb dissolved gold or silver.
- . Ores in which the precious metals are encapsulated in an inactive mineral, such as quartz, are not amenable to heap leaching because contact is not possible between the leach liquor and the metal or metal-containing compound.
- . The presence of other cyanide-interacting metals such as copper, cobalt, and zinc will reduce precious metals recovery. These metals can also complex with cyanide and will reduce the cyanide available for complexing with gold and silver.
- . For unknown reasons, manganese in silver ores causes low recovery. Many deposits of this type remain untreated because of the problem.

- . Clay minerals in ores can result in channeling of solution flow through the heap, which reduces solution contact with the metals and can result in low recovery. However, such ores can usually be leached by employing an agglomeration technique.

Ore Preparation

Mining

Cyanide heap leaching operations generally use ore obtained from open pit mining operations. Mining to obtain the ore for the leaching facilities is similar to most other open pit operations. It includes a drilling and blasting phase followed by excavation and haulage. The mined materials are classified either as ore, low grade, or waste rock. These are broadly defined as follows.

- . Ore is material containing concentrations of metals that, after leaching, will provide a profit to the operator. Materials that contain concentrations of metals that cannot be recovered at a profit are not classified as ore.
- . Low grade is material that contains metals at concentrations that are not economically recoverable, but which must be mined to provide access to the ore. This material may be placed in a separate location where it could be leached if economic conditions change. (Not all mining operations include a low-grade stockpile.)
- . Waste rock is material with little or no mineralization but which must be mined or stripped to provide access to the ore.

The objective of the mining operation is to economically select the ore, low grade, and waste materials and to transport them to their respective locations.

The initial activity in the mining operation is the drilling of blast holes (in some cases, only ripping using a dozer is needed). Besides providing a hole for the explosives, the drill or blast hole provides a method to sample the ore and to classify the material as

ore, low grade, or waste rock. A sample of the material (cuttings) from the drill hole is assayed to determine the classification of the material. The sample is usually assayed for gold and silver, and sometimes for base metals. Often a leachability test is made. Based on the assay or leach test performed in an onsite lab, the material surrounding the drill hole is classified as ore, low grade, or waste rock.

After the material is blasted, the drill hole locations are resurveyed and flagged with a color-code designating the material as ore, low-grade, or waste rock. This flagging guides the excavator/operator in determining the destination of the material. Materials are transported to the:

- . Leach pile or crushing plant, if the material is ore grade.
- . Low grade stockpile, if the material is to be stored for possible future leaching.
- . Waste rock dumps, if the material contains little or no mineralization.

In practice, the assayed drill holes are usually grouped into ore zones, low grade zones, and waste rock zones as it is impractical to selectively excavate the area represented by a single blast hole. Thus, there is some intermingling of ore, low grade, and waste rock.

The uniformity of the ore zones, low-grade zones, and waste-rock zones is an important factor in selecting the bench height to be mined. A thick, uniform ore body will allow a higher bench height, larger equipment, and a higher production rate than will a thin irregular deposit. Closely spaced holes and small equipment are required to selectively mine a thin, irregular deposit, resulting in higher operating costs and lower production rates. Other factors in selecting the mining bench height include the thickness and attitude (dip) of the ore zone, the total tons of ore (reserves) to be mined, and the daily production rate. The mining bench height normally varies from about 5

meters (15 feet) to more than 12 meters (40 feet). Generally, a thin irregular deposit will require a lower bench height while a thicker, regular, and large deposit will use a higher bench height.

Mining operations can be divided into four separate activities: drilling, blasting, excavation, and haulage. The following paragraphs describe these activities at the Pegasus Mine in Zortman, Montana, which is a large typical heap leaching operation for which information is available in the literature (Kunze and Short, 1986). The total area for the mine, leach pads, ponds, and recovery plant at this operation is approximately 130 hectares (320 acres).

Drilling is accomplished by six drills using down-the-hole hammers which drill to 7 meters (23 feet) for the 6-meter (20-foot) bench height. The drill hole spacing ranges from about 3.3 meters by 3.3 meters (11 feet by 11 feet) to 5 meters by 5 meters (15 feet by 15 feet).

Blasting uses a combination of 25 percent emulsion and 75 percent ANFO (ammonium nitrate/fuel oil mixture). This combination contains about 40 percent more energy than ANFO alone. The higher energy increases the fragmentation and provides finer material for the leach pads. This is one advantage of blasting over ripping, i.e., with blasting there is more control over breakage size. A method of delayed blasting is used to minimize the mixing of the ore and waste zones within the blast. The powder factor used is 0.75 kilograms of explosives per cubic meter (1.25 pounds per cubic yard) of material.

Front end loaders with capacities of 5 to 8 cubic meters (7 to 10 cubic yards) load the 41-metric ton (45-short ton) haulage trucks. The waste, which is produced at approximately the same rate as ore, is used to construct the base for the next year's permanent leach piles. Ore is placed in these piles without crushing. The grade is 0.79 grams of gold per metric ton (0.023 troy ounces per short ton) of ore. The cutoff for ore is 0.3 grams of gold per metric ton (0.01 troy ounces per ton) of ore.

The production rate in 1984 was established as 4.8 million metric tons (5.3 million short tons) of ore and 2.2 million metric tons (2.4 million short tons) of waste rock. The production peaked at 80,000 metric tons (90,000 short tons) per day during this period.

Information is also available in the literature for the Smoky Valley heap leach operation at Round Mountain, Nevada (Argall, 1985). At this mine, material with a gold content of greater than 0.51 grams of gold per metric ton (0.015 troy ounces per short ton) is classified as ore. The ore is crushed to approximately 1 centimeter (0.5 inch) in diameter and placed on the leach pile. During the first 9 months of 1985, ore was delivered to the leach pad at the rate of 13,101 metric tons (14,442 short tons) per day. Material ranging between 0.3 and 0.5 grams of gold per metric ton (0.008 and 0.015 troy ounces per short ton) is stockpiled in low grade stockpiles. Waste rock has less than 0.3 grams of gold per metric ton (0.008 troy ounces per short ton) and is sent to waste rock dumps. The mine produces waste to ore at a ratio of approximately 1.4 to 1.

Drilling is accomplished by four rotary drills which drill 10-meter (40-foot) deep holes ranging in diameter from 20 to 23 centimeters (7.9 to 9 inches). This depth is 2 meters (5 feet) deeper than 11-meter (35-foot) bench height. Blasting of the 5.5- by 5.5- meter (18- by 18-foot) drill hole pattern is either with ANFO or a slurry emulsion.

Excavation equipment includes 9.2-cubic meter (12-cubic yard) front end loaders, an 8.4-cubic meter (11-cubic yard) hydraulic shovel, and a 5-cubic meter (7-cubic yard) electric shovel. This equipment loads a fleet of trucks ranging from 40 to 77 metric tons (50 to 85 short tons) in capacity.

Crushing and Agglomeration

The ore is generally crushed to expose the gold and silver values. Typical ore size for heap leaching ranges from 0.64 to 0.95 centimeter (0.25 to 0.38 inch) in diameter. These sizes result from the material being crushed in two or three stages. However, if the ore is of very

low grade, such as at the Pegasus Mine, crushing may not be justified economically. Run-of-mine, uncrushed ore will require a long leach time. Crushed ore is generally of higher grade and will leach faster with better overall recovery. Crushing also produces fines, which must be handled so as not to cause a decrease in solution permeability within the pile.

At some operations, there is an excess of fines which must be agglomerated. In this procedure, an agglomerating agent such as cement or lime is added to wet ore at the rate of 2 to 4 kilograms (5 to 10 pounds) of cement per ton of ore. Water or sodium cyanide solution (which initiates the leaching action) is added to provide 8 to 16 percent moisture. The mixture is then tumbled, causing the fine ore to adhere to the coarser material in an agglomerate. The agglomerates are allowed to cure during heap building. Only minimal degradation of the agglomerated ore occurs during leaching in the heap, thus maintaining an open heap and resulting in acceptable recoveries in short periods of time.

HEAP DESIGN, CONSTRUCTION, AND OPERATION

The heap leaching facility receiving the ore from the mine generally consists of the following:

- . An impervious pad upon which the ore to be leached is piled or heaped. The pad is sloped to a sump or to a pipe system for collection of leach solution which has percolated down through the pile. During percolation, gold and/or silver are dissolved from the ore.
- . A piping/sprinkler system on top of the heap to distribute leach liquor to the heap surface.
- . A pregnant pond to hold gold-containing leach liquor. The solution is directed to the pond by ditches with impervious liners, or by pipes.
- . A pumping system to dispatch the solution to a recovery plant.

- . A process plant. Two types of process plants, carbon column or zinc precipitation, may be used. For either type of plant, a furnace is used to produce dore (gold and silver ingots). The facilities are described in greater detail in the following paragraphs.
- . A barren solution pond which stores solution from the recovery plant.
- . Overflow and/or contingency ponds.
- . Facilities for adding sodium cyanide for leaching, and for storing lime or caustic for pH adjustment (to the range of 10 to 11).
- . A pumping/piping system to return recycled leach liquor to the heap.

Design of Leach Pad and Collection System

Pad Structure

To ensure that solutions used to extract the gold and silver from the ore are retained, the pad base and the pad structure are carefully prepared to collect and drain the solution. The soil base upon which the pad is to be placed must be graded and sloped to permit containment, and to direct leach solutions to their intended destinations. The base is compacted to provide structural integrity when the pad is loaded with ore.

On top of the base, materials are placed to provide an impervious barrier to the solutions. Two or more layers are usually used. In some instances, a piping system is placed below the barriers to detect a barrier failure. The materials employed to build the impervious barrier are somewhat site specific, and can include natural local clays with very low transmissivities, bentonites, plastic sheeting, and asphalt-type materials. The barrier material must be able to withstand the weight and mechanical movement associated with placing the ore on the pad without being punctured or cracked. At some operations, geotextile fabric is placed over barrier materials such as PVC or

Hypalon to provide protection from puncturing. Several inches of permeable materials (such as crushed ore) are placed on top of the uppermost layer of the barrier to provide protection and permit ready passage of solutions to the barrier for collection and direction to the storage pond.

The Pegasus Mine in Montana uses 30 centimeters (12 inches) of compacted bentonite shale, a 30 mil PVC layer, and 46 centimeters (18 inches) of mill tailings from an old operation as the base for their pads (Roper, 1983). At Smoky Valley, in Nevada, leach pads are constructed on ground prepared with 5 centimeters (2 inches) of hydraulic asphalt, 100 to 200 mils of asphaltic rubber covered with rubber chip spray, and 10 centimeters (5 inches) of asphalt. The pad is approximately 980 meters (3,200 feet) long and 85 meters (280 feet) wide. It is inclined to one side and one end where a sump is located to receive the leach liquor by gravity.

The Smoky Valley pads are reused i.e., ore is placed on the pad, leached for a predetermined number of days, rinsed, and drained. The leached ore is then off-loaded and fresh ore is brought in for the next cycle. The construction of reusable pads is usually quite substantial so that they can withstand equipment and new ore placement with minimal damage to the barrier.

At the Pegasus Mine, the heaps are permanent. Ore is permanently located on the pad area and leached until extraction per cycle becomes uneconomic. In some operations of this type, fresh ore is added to the heap as another "lift" and the leaching process is started anew. At a leaching operations, a PVC or equivalent membrane is placed on top of the spent ore and serves as the collection barrier for leach of the new layer.

Heap Building

A variety of equipment can be used to place the ore to be leached on the pad to form the heap. Commonly used equipment includes bulldozers, front-end loaders, conveyor-stackers, and movable radial stackers. The Ortiz Mine in New Mexico uses a traveling gantry con-

veyor system to place crushed ore evenly on the pad. The size of the ore being leached influences the method of placement. Uncrushed, run-of-mine ore requires a haulage truck and dozer, while crushed ore can be handled with conveyor-stacker type units.

The height of ore heap varies from 2 to 30 meters (8 to 100 feet), but is generally between 6 to 12 meters (20 and 40 feet). The height depends on the size of the operation, available pad area, whether the pad is reusable or permanent, the tendency of the ore to degrade on leaching, and whether the heap is being handled in a series of "lifts". Special techniques of dumping and spreading the ore are used to reduce segregation of fine ore sizes during heap construction at some mining operations.

When heaps are formed using heavy equipment such as trucks and dozers, the ore can become compacted. If this occurs, ripping of the pile is conducted prior to installing the sprinkler irrigation system to increase infiltration.

At the Pegasus Mine, ore is not crushed, but is spread on the prepared pad by dozer in 6- to 9-meter (20- to 30-foot) lifts. Each lift is ripped using a dozer down to a depth of 2 meters (5 feet) from the surface prior to leaching. After leaching is completed on a lift, successive lifts of the same height are placed on the same pad up to a total height of about 30 meters (100 feet). At the Smoky Valley operation, which uses crushed ore and reusable pads, the ore is spread to a height of about 4 meters (13 feet) by front-end loader. When leaching of the heap is completed (gold content in solution drops below a predetermined level), the residue is removed by front-end loader and transported to a dump adjacent to the leaching area. The pad is then made ready for the next cycle of fresh ore.

Leaching

Once the heaps are formed and prepared for leaching e.g. by ripping, the piping or irrigation system is put in place. The leach solution can either be sprayed or ponded on the surface.

Leach solution is usually pumped through PVC pipe or equivalent from the barren storage pond to the heap. If spraying is to be used, sprinklers are placed in a grid pattern to provide overlapping coverage of the surface. The droplets from sprinklers must be small enough to give adequate coverage and distribution of the solution, but not so small as to readily evaporate or be overly influenced by wind. Ponding may be applicable in situations where fine ore is involved. However, unintentional ponding from a spraying system may indicate that a decrease of permeability in the heap has occurred. Since the leaching rate is dependent on the amount of oxygen, ponding can also produce problems with leaching efficiency.

Leach solution application rates for sprinkler systems generally range from 6 to 18 liters per square meter (0.15 to 0.45 gallons per square foot) per hour. The proper spraying rate should result in flow by gravity through the heap without producing ponding. For ponding systems, leach solution is applied at a rate about 40 liters per square meter (1 gallon per square foot) per hour. The solution has a pH of 10 or 11. Sodium cyanide content ranges from 0.2 kilograms per metric ton (0.5 pounds per short ton) of solution to as much as 2 kilograms per metric ton (4 pounds per short ton) of solution. The amount of sodium cyanide used depends on the concentration of other cyanide-consuming constituents in the ore, such as iron, copper, zinc, and sulfide. These metals and sulfide also react with cyanide making it unavailable for reaction with gold and silver.

It is important both environmentally and economically that the leach solution does not escape. The solutions percolating through the heap must be contained on the pad and drained to a collection sump. Pad grade, slope, curbs, and lined ditches are carefully maintained to ensure that loss to the environment does not occur.

At the Pegasus facility, two heap leach pads 5.6 kilometers (3.5 miles) apart are used to treat different ores. At each pile, more than 7,300 meters (24,000 feet) of 5-centimeter (2-inch) pipe deliver leach solution to 600 to 800 sprinklers. The combined sprinkler capacity for the two sites is about 300 liters per second (5,000 gallons per

minute). At one property, the barren leach solution contains 1.0 kilogram per short ton (2.1 pounds per short ton) of solution. The resulting pregnant liquor contains 0.37 kilogram of sodium cyanide per metric ton (0.74 pound per short ton) of solution. The leach solution at the other site has respective barren and pregnant sodium cyanide concentrations of 0.80 to 0.3 kilogram of cyanide per metric ton (1.6 and 0.53 pounds per short ton) of solution. The barren solution pH at both sites is 11. For the year 1982, it was estimated that sodium cyanide was consumed at a rate of 0.4 kilogram per metric ton (0.7 pound per short ton) of fresh ore and that 5 to 10 percent of the solution was lost to evaporation.

The Smoky Valley leach pad is subdivided into 24 sections with separate, discrete, solution distribution systems. At any one time, 19 sections are under leach, one is being washed, one is draining, one is being unloaded, one is being loaded, and the last is open. For those sections under leach, solution containing 0.5 kilogram per metric ton (1 pound per short ton) of solution at a pH of 10 is sprayed on the ore for about 40 days. Each section has 21 sprinklers, each covering about 116 square meters (1,250 square feet). Following leaching, the ore is washed with fresh water for 2 days and another 2 days are allowed for draining. Following the draining period, 2 days are used to unload the heap, and 2 days are required to reload the pad with fresh ore. About 0.3 kilograms (0.6 pounds) of sodium cyanide and 0.2 kilograms of sodium hydroxide per metric ton of ore (0.3 pounds per short ton) are consumed in the leach cycle. The resulting pregnant solution contains 0.78 gram (0.025 troy ounce) of gold and 0.2 kilogram (0.3 pound) of sodium cyanide per metric ton (short ton) of solution.

Metal Recovery

The next step in the process is to remove the values from the solution and convert them to metal. Solutions coming from the heap are stored in the pregnant pond which is sized to hold the process solution volume plus the runoff and leachate from an unusually high precipi-

tation event such as a 100-year storm. The sizing of the pregnant pond also depends on water balance (whether the site gains water from precipitation or excessive washing or loses water due to evaporation in a dry climate).

The solution is pumped from the pregnant liquor pond to a process unit. Two types of process plants can be used. A carbon column process plant consists of a series of columns containing activated charcoal. As the solution is passed through the charcoal, gold is adsorbed onto the carbon along with the cyanide which is complexed with gold. In the Merrill Crowe process, which uses precipitation on zinc, the solution is clarified, deaerated, and reacted with zinc shavings or powder to precipitate the gold by displacement with zinc. In either process, after the gold is removed from solution, the remaining solution is sent to a barren solution storage pond. This pond is generally sized to hold approximately one-third of the total system solution volume plus precipitation due to extreme storm events.

When carbon columns are used, the values must be stripped from the carbon (which is then reactivated and recycled) and converted to metal. This is usually done by passing a hot, concentrated cyanide solution through the carbon to desorb the gold and silver complexes. The resulting solution can then be treated either by electrolysis or by the Merrill Crowe process. In the case of electrolysis, also called electrowinning, stainless steel wool is used as the cathode. The strip solution is circulated through the cell and the gold and silver are plated onto the wool. The loaded wool is removed periodically, melted in a furnace, and cast to dore bars (a mixture of gold, silver, and impurities). This is generally sent to a refinery for metal separation and preparation of high grade gold and silver.

Each of the Pegasus leach pads hold approximately 40 million liters (10 million gallons) of leach solution. The ponds receiving the solution are designed to contain 15 to 20 million liters (4 to 6 million gallons). To prevent loss of solution by leakage, the ponds are lined with a fine rock base covered with 30 centimeters (12 inches) of compacted bentonitic shale which is protected with a layer of 36

mil, 1000 denier, 10 x 10 reinforced Hypalon. Solution from the pond is pumped through clarifying filters to a deaeration tower. Clarification i.e., the removal of solids, helps the purity and grade of the precipitate, while deaeration removes dissolved oxygen and reduces zinc consumption. Both processes prepare the solution for Merrill Crowe precipitation by reaction with metallic zinc. Pegasus indicates recoveries as high as 90 percent from solution even at solution levels as low as 0.240 grams of gold per metric ton (0.007 troy ounces per short ton) of solution. After precipitation of gold and silver, the solution is sent to the barren storage pond where lime and/or caustic, and sodium cyanide briquettes are added to prepare the solution for transfer back to the heaps for more leaching.

The gold and silver precipitated with zinc is melted to dore in a manner similar to treating the steel wool cathodes from electrowinning. At the Pegasus operation, the precipitate from the Merrill Crowe process, averages about 20 percent gold and silver. It is melted along with appropriate fluxes in propane fired, 56.7-kilogram (125-pound) capacity furnaces. The dore produced at the end of 1982 assayed about 32.5 percent gold, 62.5 percent silver, and 5 percent slag. The dore produced is sent to a large refinery for conversion to pure gold and silver. The slag which is produced and skimmed from the melt before casting the dore bar contained about 300 grams (9 troy ounces) of gold and 812 grams (23.7 troy ounces) of silver per metric ton (short ton). The slag is crushed and screened, sampled for precious metals content, and sent to an outside refinery for reclaim of its values. In 1982, approximately 160 metric tons (177 short tons) of slag were sent for refining and recovery of its contained gold.

At Smoky Valley, solution from the heap sections under leach is collected in a 9.5-million liter (2.5-million gallon) holding pond. Pregnant solution, which contains approximately 8.6 grams of gold per metric ton (0.25 troy ounce per short ton), is then pumped to carbon columns. There are five columns arranged in series. Each column is 3.6 meters (12 feet) in diameter, 2 meters (8 feet) high, and contains about 3,000 kilograms (7,000 pounds) of 12 X 30 mesh carbon. Solution

is introduced to each column such that there is counter-current flow through the carbon. To achieve a counter current flow, the carbon is advanced by water eductors in an upstream direction at the rate of 1.1 metric tons (1.2 short tons) per day. The carbon removed from the first column each day contains about 8,600 grams per metric ton (250 troy ounces per short ton) of gold and silver. Barren solution from the number five column is treated with cyanide and caustic and is returned to the heaps for more leaching.

The gold and silver loaded carbon from the adsorption section is transferred to a preheat vessel and then to the stripping vessel. Strip solution contains 0.5 percent sodium hydroxide and 0.25 percent sodium cyanide and is heated to 140 degrees Centigrade ($^{\circ}\text{C}$) (280 degrees Fahrenheit ($^{\circ}\text{F}$)). The strip solution, assaying about 300 to 800 grams of precious metal per metric ton of solution (10 to 15 troy ounces per short ton), is then processed through the electrowinning circuit. Steel wool cathodes are used and when loaded they are melted with appropriate fluxes (borax, nitrate, and silica sand), in crucible reduction furnances. The iron is slagged off and dore buttons of 65 percent gold and 34 percent silver are produced. These are remelted and cast into 30,000 to 34,000 gram (1,000 to 1,100 troy ounce) bars, which are shipped to a refinery for final treatment. Approximately 2.4 million grams (79,000 troy ounces) of gold in dore is produced each year, which represents about 63 percent of the gold contained in the ore treated. Silver recovery is about 30 percent. The stripped carbon is reactivated in an indirectly fired rotary kiln at 650°C (1200°F), washed with nitric acid to remove carbonates and/or heavy metals, and recycled to the columns.

IMPOUNDMENT DESIGN AND CONSTRUCTION

Basis of Design for Process Impoundments

The design basis for ponds is site specific and depends on terrain and operating practice. However, all ponds must prevent any loss of solution either from leakage or overflow. Pond design criteria include minimum storage capacity, operating capacity, storage for runoff, and

freeboard. The ponds must also have an impervious liner to prevent leakage through the bottom and sides. Capacity factors that have been used for pond design are presented in Table 1.

Options for pond design and construction include pond geometry as to length, width, and depth; nature of the pond liner (clay, synthetic, single, or double); and aspects of the operation such as inflow, pumping arrangements, and access requirements.

Materials Used in Construction

Materials used for pond liner construction on a prepared, compacted soil base include clay, synthetic liners, and sized and graded gravels. Clays are not generally used in direct contact with solution because gold can be adsorbed onto the clay which would represent a loss of value. Synthetic PVC or Hypalon liners are generally used as the upper most layer. Some operations have used double, or even triple liners. When two or more layers of synthetic material are used, they may be separated by as much as 30 centimeters (12 inches) of pea gravel or other material. A collection pipe system is sometimes placed in the gravel to detect any leakage through the upper layer.

Maintenance Programs

The ponds are usually drained and inspected visually at least once each year for punctures or for breaks in the glued seams. Pipe under-drains for leak detection are usually checked on a daily basis. If a leak is detected, appropriate steps can be taken to correct the problem. In some cases leak testing is done by monitoring pond levels with surveying equipment and comparing that data to evaporative loss for the same period.

Runoff Diversion Provisions

Surface water runoff is diverted around both the pond areas and the entire process facility. Unlined diversion ditches are sized to handle a major 100-year climatic event or to meet State requirements.

TABLE 1
TYPICAL CAPACITY FACTORS FOR DESIGN OF HEAP
LEACH OPERATION PROCESS IMPOUNDMENTS

	<u>Pregnant Solution Pond</u>	<u>Barren Solution Pond</u>
Operating Volume	1/3 of final capacity	1/3 of final capacity
Operational Surge	Contain draindown or draindown and rinse volume	None
Climatic Surge	Contain 100-year, 24-hour storm runoff from pad and on pond	Contain 100-year, 24-hour storm on pond
	or	or
	Contain 100-year, 1-year runoff from pad and precipitation on pond	Contain 100-year, 1-year precipitation on pond
	or	or
	Contain snowmelt from a 100-year snowpack on pad and pond.	Contain snowmelt from 100-year snowpack
Safety Factor	0.3 meters (1 foot) of freeboard	0.3 meters (1 foot) of freeboard

Source: Modified after Hutchison, 1985.

SAFEGUARDS

The type of safeguards selected at heap leach operations depends on legal requirements, the proximity to populated areas, degree of interconnection between surface and ground water systems, and adjacent land uses. Some backup systems that have been employed are discussed below.

- . Auxillary power capacity may be installed to provide continuous pumping to maintain proper pond levels in the event of failure of the regional power system or onsite generating system.
- . Emergency ponds may be installed to prevent spills resulting from severe storms or inadequate freeboard.
- . Leak detection systems under pads and ponds have been required by some regulatory programs because of concern over liner types, adequacy of seaming, and possible damage to the pad during loading. Some operations have been constructed with double or even triple liners. Leak detection systems in use include down-gradient monitoring wells and direct monitoring techniques such as pipe underdrains.
- . Spill containment plans outlining procedures for the treatment and handling of spilled materials and notification of authorities can help minimize overall impact of a spill.

SITE ACCESS

Human

Areas containing exposed process solutions are generally fenced with a 2.4-meter (8-foot) tall chain link fence topped with barbed wire and posted with appropriate warning signs. The entire site may also be fenced with a standard four-strand, barbed-wire fence.

Wildlife

Wildlife access is controlled by the use of fences. Other measures that have been used to protect wildlife are netting or flagging over ponds and covering ditches with rock. A 2.4-meter (8-foot) tall woven wire fence topped with barbed wire is commonly used to exclude large mammals such as elk and deer. Livestock and the larger fur-bearing mammals (coyote and grey fox) are also kept out with this type of fence. Similarly designed gates provide human access while preventing these animals from bypassing the fence.

The placement of flagging or netting over open ponds and rock covers over drainage ditches restricts access to these facilities for mammals that can climb over, go through, or dig under the fence, and for birds. A fine mesh netting over ponds, and a mixture of large and small rock in the ditches, is the most effective combination.

HANDLING AND DISPOSAL OF CYANIDE CONTAINERS

Sodium cyanide (NaCN) is available in two widely used forms: a briquette form and a granular form. Both forms can be delivered to the operating facilities in either 208-liter (55-gallon) drums (usually used at smaller operations) or Flo-Bin containers (usually used at larger operations). Proper education and training about health hazards, basic safety precautions, and proper handling, storage, and disposal procedures is of utmost importance not only for the safety of the workers but also for the success or failure of an operation (Stanton et al., 1985). Appendix C contains more information about the human health effects of cyanide.

Safety Precautions

The basic safety precautions for people working with sodium cyanide include the following:

- . Wearing approved dust respirators when there is danger of inhaling cyanide dust. Respirators are approved by the Mining Enforcement and Safety Administration or by the National Institute for Occupational Safety and Health (NIOSH).
- . Avoiding skin contact with cyanides by wearing protective gloves when handling solid cyanides and rubber gloves when handling cyanide solutions, and by washing hands and gloves thoroughly with running water after handling cyanides.
- . Wearing approved chemical splash goggles when handling cyanide solutions and when there is danger of splashing.
- . Sweeping up spilled cyanide and placing it in suitable, clearly labeled containers; treating the contaminated area with dilute hypochlorite solution to destroy the residual cyanide; then flushing the area with water.
- . Preventing acids or weak alkalies from contacting sodium cyanide.
- . Storing sodium cyanide in dry, well-ventilated areas and keeping containers closed and their contents dry.
- . Posting warning signs, no smoking signs, and no eating signs where cyanide is being used.

Handling Cyanide Containers

In order to prevent the formation of hydrogen cyanide gas, drums of sodium cyanide are stored in dry buildings segregated from acids, weak alkalies, and strong oxidizing materials such as nitrates. Other precautions taken include removing from storage only the quantity of cyanide required for immediate use, opening cyanide drums in the areas in which the cyanide is to be used, ventilating the area, replacing container covers immediately, and picking up any spillage. The same safety precautions apply to the use of Flo-Bin containers, although they may also be stored outdoors.

Treatment and Disposal of Cyanide Containers

According to U.S. Department of Transportation (DOT) regulations, steel drums that contained sodium cyanide are not returnable and cannot be reused for the transportation of other wastes except under special conditions approved by the EPA. Because some residual cyanide can be expected to occur in the drums, they are considered by the EPA's regulations as an acutely hazardous waste and are subject to Federal regulations for the management of hazardous wastes (40 CFR 261; 49 CFR 173.28).

Procedures used for the handling and disposal of spent cyanide drums are as follows:

- . Each empty drum is flushed with a large volume of water and drained to an operation pond or other facility which would introduce the solution back into the process system. Each drum is washed at least three times until no cyanide remains in the drum.
- . The labels on the drum are removed or obliterated. The drum is then crushed or mutilated so that it cannot be reused.

Following these procedures, the drum is considered nonhazardous and may be disposed of accordingly. Approval of the plan and the disposal site (such as a local sanitary landfill) is obtained by local officials prior to implementation of operations. Onsite disposal of the spent barrels is also possible when local and State regulators approve.

Handling Spills

Spilled material can be shoveled and/or swept into a drum or suitable container. In order to inhibit the formation of hydrogen cyanide gas, the following precautions can be taken:

- . Covering the spill to reduce the solution of sodium cyanide and reduce run-off.
- . Rinsing the area with dilute hypochlorite solution to destroy the cyanide.

- . Adding a small amount of caustic (0.6 kilograms per 100 liters or 5 pounds per 100 gallons of water) to keep the pH of a sodium cyanide solution around 12 and minimize hydrogen cyanide formation.

MONITORING

For many operating heap leach projects, monitoring programs are extensions of sampling and data gathering efforts established during environmental baseline programs. Although monitoring cannot control a failure, it can provide early warning that a problem exists so that appropriate mitigation can be identified and undertaken.

The two basic types of leak detection systems are monitoring wells and visual inspection systems. Most visual inspection systems incorporate variations of the French-drain principal. In these systems, a grid of perforated piping is contained within an aggregate filter under the liner, or between two liners. This allows leaking solution to drain to an outlet downgradient of a heap, for visual identification of leaks. Various types of leak detection systems are described below.

Monitoring Wells

Potentially affected aquifers can be monitored by the sampling of wells and springs. Monitoring wells should be down-gradient from the cyanide leaching operation, although upgradient wells may be sampled as indicators of background conditions. Commonly, sampling is conducted quarterly. The selection of parameters to be analyzed is governed by State agencies and depends on site-specific conditions. In order to be effective, monitoring wells should be as close to the operations as possible in locations where subsurface waters will be intercepted.

Problems with monitoring wells may arise in historical mining districts where underground mine workings alter the expected flow direction and lead to improper placement of the wells. Problems can also occur in situations where the slow rate of ground water movement results in a time lag that can lead to significant soil volumes being contaminated before monitoring detects the pollutant.

Lysimeters

Lysimeters are used for detecting liquids in unsaturated or partially saturated zones of the soil. Lysimeters generally detect leaks earlier than do monitoring wells. One type of lysimeter consists of a porous ceramic cup in which a vacuum is created to draw in from the unsaturated or partially saturated soil zone. The liquid is then forced to the surface for collection and analysis. Although lysimeters cannot locate a leak, in sufficient numbers they can help evaluate the location of a contaminant plume. Problems with lysimeters have been documented and include plugging, inadequate sample volumes, and corrosion.

Leachate Collection System

A leachate collection system can be used to detect and sample leaking solution immediately beneath the liner of the leach pad or process pond, and employs the French-drain principal. The leachate collection system commonly consists of a grid of perforated piping within an aggregate filter under or between liners. Solution drains downgradient through the piping and leakage is visually detected. Although such systems can provide a prompt indication of leakage, they can be expensive and may plug with time.

Grid Leak Detection System

The grid leak detection system, designed by Johnson (1983) consists of a grid network of wire placed under the liner. To our knowledge this system has not been used, however this technology may be applied in the future. In this system, any leakage beneath the liner would cause electrical property changes which would be detected by a data logger. Although this system would be capable of detecting the location of a leak, the leaked material would be unavailable for sampling.

CLOSURE OF HEAP LEACH FACILITY

Decommissioning

Spent Leach Heap Piles

Rinsing of the heap is generally used to destroy residual cyanide prior to closing spent heaps. The rinsing procedure usually consists of applying either fresh water or an alkaline solution containing chlorine to the heap. The requirements for neutralization of cyanide in spent heaps vary by State (refer to Appendix B, Table B-11). The resulting leachate is treated to destroy cyanide and the effluent is recycled through the heap. This process is repeated until the cyanide concentration in the leachate is below the level required by regulatory agencies. Methods for neutralizing cyanide in water are described in Appendix B. Where a fresh water rinse is used (Nevada), the operator is required to rinse with water until the pH of the effluent is 8.5 for three consecutive days. In the few cases where the pads are reused, such as Smoky Valley, the spent ore is hauled and disposed in an area suitable for a permanent repository. The regulations for disposal vary by State; in Nevada, where Smoky Valley is located, a catch basin downgradient from the spent ore is required so that leachate may be sampled.

Process Cyanide Solutions

Barren solution, and the rinsing solution from neutralization of the spent ore heaps are subject to cyanide destruction upon facility closure. Cyanide destruction methods are based on oxidation (alkaline chlorination, hydrogen peroxide, Inco process) and biological processes. The methods typically used at heap leaching operations are alkaline chlorination and hydrogen peroxide. The alkaline chlorination method destroys cyanide ion, hydrogen cyanide, and cyanide from most metal cyanide complexes with the exception of iron cyanide complexes. The hydrogen peroxide method destroys cyanide ion, hydrogen cyanide, and cyanide in copper, zinc, and nickel cyanide complexes. If copper is added, iron cyanide complexes may be precipitated. An added benefit of hydrogen peroxide is metals are precipitated as hydroxides. The major

treatment processes that may be used at leaching operations are summarized in Appendix B. After the neutralization is completed, the solution is evaporated or sprayed on an environmentally suitable area.

Reclamation

Reclamation of a heap leach site involves disposal of waste material, dismantling of buildings and roads, decommissioning of heaps and ponds, grading, topsoiling, and revegetating so that the land is returned to beneficial use. The degree to which specific sites must be reclaimed varies by State. In some states, including South Dakota, reclamation requirements are decided on a case-by-case basis. In general, reclamation should reduce or minimize erosion, provide stable slopes, and reproduce natural vegetation levels. Using appropriate reclamation technology, vegetation can be restored to most sites, as long as a stable surface is provided, topsoil is available, and appropriate seeding methods are used.

The mine pit is generally not backfilled. Therefore, it is important that slopes be stabilized through methods such as revegetation of the benches to prevent sloughing and reduction of slopes. Heaps and waste piles may or may not be revegetated, depending on previous and future land uses. In either case, however, they can be stabilized and designed to minimize erosion. This is particularly important if waste piles are located in drainages. Roads also may remain, depending on the desire of the landowner. If left in place, banks can be revegetated to protect against erosion.

CHAPTER 3

EXISTING ENVIRONMENT OF THE BLACK HILLS

GENERAL DESCRIPTION

The Black Hills are an isolated extension of the Rocky Mountains located on the west-central border of South Dakota (see Figure 1). They extend 190 kilometers (120 miles) from north to south and between 60 and 80 kilometers (40 and 50 miles) from east to west. Most of the Black Hills are located in South Dakota with the western edge extending a short distance into Wyoming. The Black Hills are the only area of mountainous terrain in the western Great Plains. The uplifted hills are surrounded by rolling foothills and broad valleys which gently dip to the prairies.

Since the area was first settled in the 1830's, forestry and mining have been the two dominant industries in the Black Hills. However, over the past few decades, recreation and tourism have become increasingly important to the economy of the area.

The flora of the Black Hills contains a diverse assemblage of plant species representative of the Rocky Mountain region, the northern boreal forest, the eastern Great Plains, and the eastern deciduous forest. Ponderosa pine is the predominate timber species and covers nearly 90 percent of the Black Hills. The regional wildlife resources are diverse, with elk, deer, and pronghorn antelope as the major game species. Local wildlife composition is strongly influenced by the variety of topographic conditions and vegetation types present.

The higher portions of the hills rise from 900 to 1,200 meters (3,000 to 4,000 feet) above the surrounding plains and reach an altitude of more than 2,000 meters (7,000 feet) at Harney Peak. The hogback ridges of the Cretaceous Fall River sandstone form an outer encircling rim to the Black Hills. Within the hogbacks, the Red Valley extends completely around the uplift. The valley ranges in width from a narrow band to several miles at the widest point. Situated above the Red Valley are the Foothills and Minnekahta Plains which consist of

broad, rolling plains marking the transition from plains to mountainous topography. The Limestone Plateau, which is an escarpment that is widest along the northwestern edge of the Black Hills lies above the Foothills and Minnekahta Plains. The central area is a granitic and metamorphic core highly dissected by ridges and mountains scattered among large parklike valleys with canyons extending out to the north, east, and south.

The Black Hills uplift is drained by relatively small streams radiating from the divide formed by the western part of the Limestone Plateau. Streamflows are greatest where drainage is toward the north and east. Many streams disappear or lose much of their flow as they cross the tilted sedimentary beds near the perimeter of the uplift. Two major drainage basins lie in the Black Hills. To the south lies the Cheyenne River basin and to the north is the Belle Fourche basin. Water yield is greater in the northern Black Hills than in other areas of the hills.

Climate

Although the climate of the Black Hills is strongly influenced by air masses from the Gulf of Mexico in the summer and by polar air masses in the winter, this isolated group of forest-covered mountains has a climate of its own. Warm chinook winds and frequent sunny skies make the Black Hills area the warmest part of South Dakota in the winter. During summer, the higher elevation of the Black Hills results in the area having cooler temperatures than the rest of the state. Average monthly temperatures in Lead, South Dakota range from -5°C (23°F) to 20°C (68°F) (Table 2) (Ruttner, 1980). Temperature extremes vary from -33°C (-27°F) recorded in December 1968 and 35°C (95°F) recorded in June 1970 and August 1969 (Ruttner, 1980). The freeze-free season is quite short high in the Black Hills where brief freezing has been known to occur at any time of the summer. The growing season ranges from 50 days at the highest elevations to a maximum of 140 days at the lowest elevations, with an average of 119 days (Spuhler et al., 1971).

TABLE 2
MEAN MONTHLY TEMPERATURES AND PRECIPITATION
FOR LEAD, SOUTH DAKOTA 1951-1974

<u>Month</u>	<u>Monthly Average Temperature</u>		<u>Monthly Average Precipitation</u>		<u>Monthly Average Snow, Sleet</u>	
	<u>°C</u>	<u>(°F)</u>	<u>mm</u>	<u>(inches)</u>	<u>mm</u>	<u>(inches)</u>
January	-4.67	(23.6)	30.2	(1.19)	389	(15.3)
February	-2.89	(26.8)	40.6	(1.60)	554	(21.8)
March	-1.06	(30.1)	54.6	(2.15)	681	(26.8)
April	4.22	(39.6)	96.5	(3.80)	770	(30.3)
May	10.3	(50.5)	117	(4.62)	190	(7.7)
June	15.7	(60.3)	109	(4.31)	33	(1.3)
July	19.3	(67.7)	63.5	(2.50)	0.0	(0.0)
August	19.5	(67.1)	56.9	(2.24)	0.0	(0.0)
September	13.4	(56.2)	49.0	(1.93)	64	(2.5)
October	8.39	(47.1)	36.8	(1.45)	230	(9.1)
November	0.89	(33.6)	40.9	(1.61)	455	(17.9)
December	-2.67	(27.2)	39.4	(1.55)	505	(19.9)
Year	6.78	(44.2)	735.3	(28.95)	3,876	(152.6)

Source: Modified from Ruttner, 1980.

Average precipitation varies from 410 millimeters (16 inches) in the southern portion of the Black Hills to almost 740 millimeters (29 inches) in the northern portion (Table 2). Rain and snow are often formed when the prevailing winds are abruptly forced up the mountain-sides. Most of the yearly precipitation occurs from April through September, with the heaviest events in April, May, and June in the form of thunderstorms associated with hail (Fox, 1984). There is much local variation in rainfall, and although midsummer precipitation is light, there are generally daily local showers at variable locations in the Black Hills. A rainfall of 25 millimeters (1 inch) or more may be expected on the average of about once a year, and storms depositing 50 millimeters (2 inches) or more of rain per hour occur about once in 10 years. Annual snowfall averages almost 4 meters (13 feet) (Table 2), with a snow cover of 30 millimeters (1 inch) or more on an average of 68 days per year. Net annual evaporation loss is approximately 300 millimeters (12 inches) (Montgomery, 1985).

The area is subject to violent thunderstorms. An unusual and excessive rainfall occurred in June 1972, causing a great flood in the Rapid City area. An almost stationary group of thunderstorms formed over the eastern Black Hills and produced nearly 380 millimeters (15 inches) of rain in a 6-hour period. The resulting floods were the highest ever recorded in South Dakota and at least 18 of the 27 streams where peak flows were computed experienced flows that exceeded the 50-year flood (Schwarz et al., 1975). The rainfall amount constituted about 65 percent of the probable maximum precipitation for a 26-square-kilometer (10-square-mile) area (Schwarz et al., 1975). This flood produced the greatest loss of life in the United States from a single flood event since 1927, with 236 deaths and a total estimated damage of \$150 million.

History

Gold mining activities are not new to the Black Hills area. Some prospecting and minor production of placer gold may have begun as early as 1834 in the northern Black Hills, but large-scale placer operations and the discovery of the first lode claims did not take place until

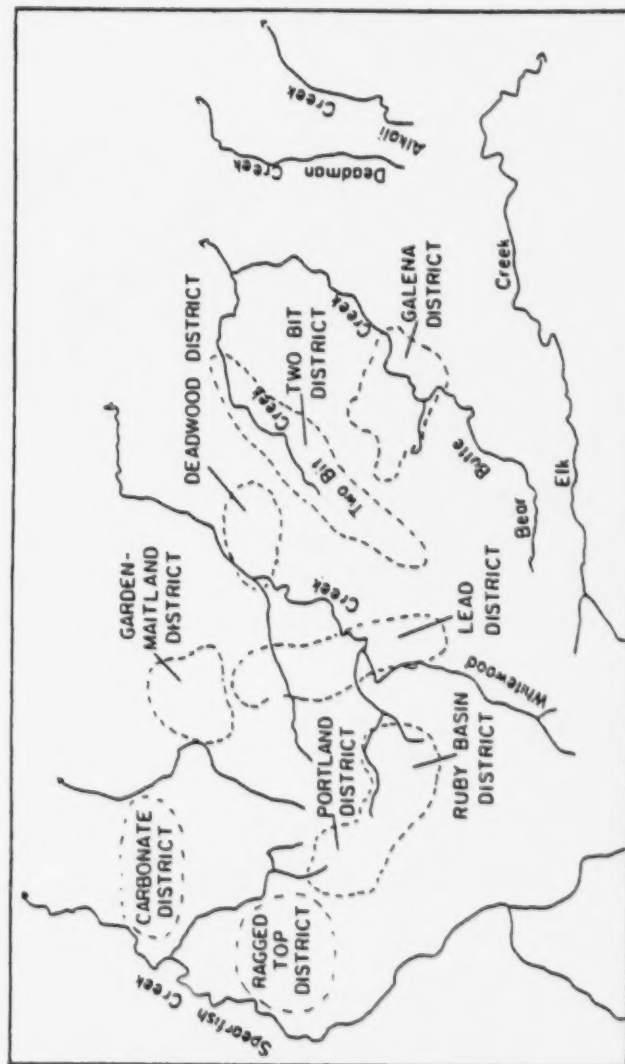
gold was discovered in French Creek by a party of prospectors accompanying an expedition organized by General George Custer in 1876. At the time, prospecting was difficult because the Black Hills were inhabited by the Sioux Indian Nation. However, in February 1877, a treaty was negotiated with the Indians and mining activities flourished.

Black Hills gold production boomed from 1898 to 1917, with production of almost 12 million grams (400,000 troy ounces) of gold in good years. The decline just prior to World War I occurred because costs for labor and supplies skyrocketed with the pending war. All mining ceased except in the Homestake Mine near Lead, South Dakota. The Homestake Mine was an important gold discovery made by the Manual brothers in 1876. The Manual's sold their claim to California Senator George Hearst for \$70,000. Hearst acquired and consolidated properties and Homestake became the most prolific gold producer in North America. The Homestake Mine has produced in excess of one billion grams (35 million troy ounces) of gold (Coin Lake Gold Mines Annual Report, 1985). Homestake is located in the Lead mining district (Figure 4).

Second to Homestake in gold production in South Dakota was the Golden Reward mine located 5 kilometers (3 miles) from Lead in the Bald Mountain mining area. The Bald Mountain mining area includes the Portland and Ruby Basin mining districts (Figure 4). Mining occurred from 1888 through 1918 and 40 million grams (1.3 million troy ounces) of gold were produced. The Golden Reward Mine mined the oxidized "red ores" which were followed underground until the ore changed to a more refractive blue ore which could not be successfully treated with the technology of the times (Coin Lakes Gold Mines Limited Annual Report, 1985).

During the turn of the century, mining activities were occurring in all of the major mining districts in the northern Black Hills (Table 3). The Garden-Maitland district produced gold and silver from vertical fractures in the basal Deadwood conglomerate and from replacement deposits in the lower contact zone (see geology discussion later in

FIGURE 4
LOCATION MAP OF NORTHERN BLACK HILLS MINING
DISTRICTS SURROUNDING THE LEAD-DEADWOOD DOME



(SHAPIO AND GRIES, 1970)

TABLE 3
MAJOR MINES IN THE NORTHERN BLACK HILLS

<u>Mine and District</u>	<u>Years of Operation</u>	<u>Gold Production^{a/} (Dollars)</u>
Dakota Mining and Milling- Portland District	1902-1906	544,000
Gilt Edge Mine - Galena District	1900-1916, 1937-1941	749,000
Golden Reward - Lead District	1887-1913	21,000,000
Hidden Fortune - Lead District	1904-1905	188,000
Homestake - Lead District	1878-to date	980,089,720 grams (31,510,612 oz.)
Horseshoe Mogel - Ruby Basin District	1894-1919	7,000,000
Imperial - Portland District	1902-1906	Not available
Maitland and predecessors - Garden-Maitland District	1903-1906, 1930's	2,851,600 grams (91,681 oz.)
Bald Mountain-Portland- Trojan - Portland and Ruby Basin District	1908, 1912-1923 1930's, 1946-1959	12,000,000
Reliance and New Reliance - Portland District	1902-1916	610,000
Spearfish-Victoria- Ragged Top District	1901-1905, 1912	972,000
Wasp No. 2 - Lead District	1897-1917	2,767,000

^{a/} Unless otherwise noted

Source: Parker, 1981.

this chapter) from 1880 through 1910. In the Ragged Top district, gold was discovered in 1896 and production ended in 1916. The gold was produced from Pahasapa Formation deposits.

In the Galena district, gold was discovered in Bear Butte Creek in 1875. The placer deposits were largely disappointing, so prospectors began looking for lode ore. The ore that was discovered was rich in silver and lead as well as gold. The ore was in galena (lead ore) rather than the limestone carbonate ore found in the other districts. The largest mine in the Galena area was the Gilt Edge Mine along Strawberry Gulch. It was in operation from 1900 to 1902, 1905 to 1916, and 1937 to 1941. The operation in the 1940's was the third largest mining operation in the Black Hills.

Free-milling gold ores were played out by the end of the 1880's, so various processes were developed to mill the ore to extract more gold. In the late 1880's J.S. McArthur and R.W. Forrest developed a cyanide process for removing gold from oxidized and refractory ores. In the Black Hills, it was originally used to extract gold from tailings of the mercury amalgamation process, but was later used as a cyanidization process alone. Once the cyanide liquid was charged with gold, it was run over zinc shavings so the gold would precipitate out. As the cyanide process was refined, increased amounts of gold could be extracted from all but the most refractory deposits.

Past mining and milling operations have produced numerous tailings and waste piles in the Black Hills. Mining-related pollution in Whitewood Creek was reported as early as the turn of the century (Parker, 1981), and tailings were discharged directly to nearby streams for nearly 100 years. Recent regulations controlling mining and mineral processing together with improved technology, have made mining far less destructive to the environment than in early days.

Selected Watersheds

Three watersheds located in the northeastern Black Hills were selected for examination: Spearfish Creek, Whitewood Creek, and Bear Butte Creek (see Figure 1). These were selected on the basis of

proposed mining activity, impacts of past mining, socioeconomic patterns, and variation in physical and environmental characteristics.

Spearfish Creek represents a baseline drainage where mining, both past and present, has not severely impacted the area. Currently, there is one active mining operation in the area with several other projects proposed. The Spearfish Creek drainage is relatively undeveloped with some recreational use and summer homes.

The Whitewood Creek drainage was the site of extensive historical mining activity. Over time, there were approximately 65 mills in the Whitewood Creek watershed. These mines and mills severely impacted water quality in the drainage. A 29-kilometer (18-mile) segment of Whitewood Creek is currently on the National Priorities List as a hazardous waste site under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) because of concern about the toxicity of heavy metals in mine tailings previously deposited along the length of the creek. The only remaining active mine is Homestake, North America's largest gold mine. The watershed is also a more populated area, and contains a wastewater treatment plant discharging to the creek north of the town of Deadwood.

Bear Butte Creek has had intermittent mining activity since 1875 when placer gold deposits were first discovered. Currently, no active mining is occurring, but operations have been proposed. The Bear Butte Creek drainage represents an essentially undeveloped area.

The existing environment in the study area is described below. Specific discussions on the individual watersheds are included where appropriate.

GEOLOGY

Regional Geology

The Black Hills uplift is a north- to south-oriented doubly-plunging anticline formed during the formation of the Rocky Mountains 60 to 65 million years ago. The uplift consists of an eastern and western block, with the eastern block structurally higher than the western

block. The blocks are separated by the Fanny Peak monocline (DeWitt et al., 1986). The central core of the anticline consists of Precambrian (more than 600 million years old) metamorphic and Tertiary (63 million to 1 million years old) igneous rocks and is surrounded by concentric outcrops of Paleozoic (600 million to 230 million years old) and Mesozoic (230 million to 63 million years old) sedimentary rocks which dip away from the core (Figure 5). The Precambrian metamorphic rocks and the Paleozoic and Mesozoic sedimentary rocks have been intruded by a series of west-northwest trending stocks, laccoliths, and dikes of Tertiary age. Erosion of the uplifted sedimentary strata has exposed the older core rocks and created the present topography of the Black Hills.

Geology of the Study Area

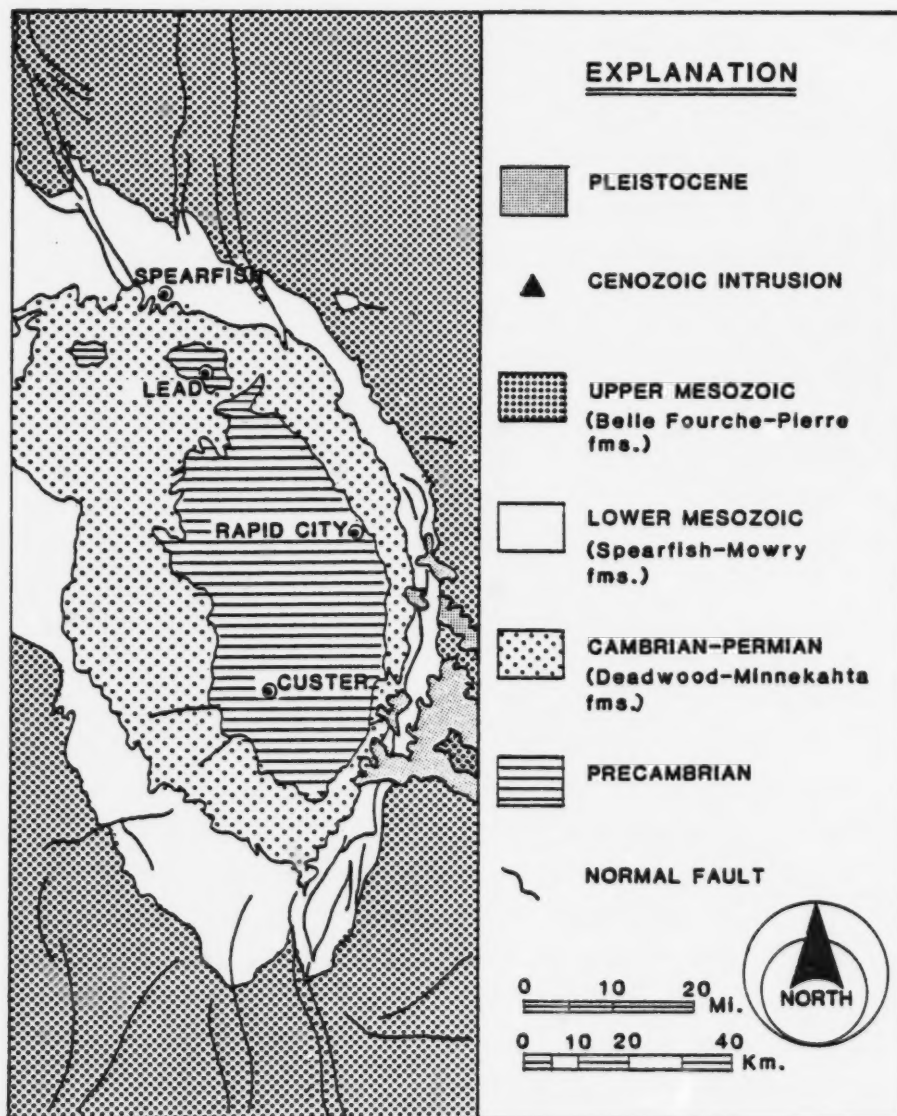
The Spearfish Creek, Whitewood Creek, and Bear Butte Creek watersheds are located on the northern flank of the anticline in the northern Black Hills and extend north and northeast to the Great Plains. The headwaters of these watersheds originate in the Precambrian core and the creeks flow across outcrops of the Paleozoic and Mesozoic sedimentary rocks and on to the Great Plains.

Stratigraphy

The Precambrian rocks in the northern Black Hills consist of metamorphic, igneous, and sedimentary rocks with a total stratigraphic thickness of about 600 meters (2,000 feet) (Figure 6). The oldest formations are the Poorman and the Homestake (Slaughter, 1968), which are ankeritic carbonates and iron-magnesium carbonates, respectively. The Homestake Formation is exposed in the Lead-Deadwood area and contains rich gold-bearing ore deposits. The younger Precambrian formations are the Ellison, Northwestern, Grizzly, and Flag-Rock, which are dominantly argillaceous rocks with some quartzites.

The Paleozoic rocks lie unconformably on the Precambrian. The Deadwood Formation is an interbedded sandstone with a basal quartzite conglomerate and an upper sandstone and quartzite. These two members are ore-bearing and locally are often water-bearing. The Deadwood

FIGURE 5
GENERAL GEOLOGY OF THE BLACK HILLS



(FELDMANN AND HEIMLICK, 1980)

FIGURE 6

GENERAL STRATIGRAPHIC SECTION OF BLACK HILLS AREA

		FORMATION	SECTION	THICKNESS IN METERS		
TERTIARY	QUATERNARY	SANDS AND GRAVELS		0-15		
	PLIOCENE	OSALLALA GROUP		0-30		
	MIOCENE	ARIKAREE GROUP		0-150		
	OLIGOCENE	WHITE RIVER GROUP		0-180		
	PALEOCENE	FORT UNION FORMATION	TONGUE RIVER MEMBER		0-130	
			CANNONBALL MEMBER		0-70	
			LUDLOW MEMBER		0-110	
			?	HELL CREEK FORMATION (Lance Formation)		130
	CRETACEOUS	UPPER	FOX HILLS FORMATION		8-60	
			PIERRE SHALE		370-600	
Sharon Springs Mem.						
NIOBRARA FORMATION				30-70		
Turner Sand Zone						
CARLILE FORMATION				120-230		
Well Creek Sands						
GREENHORN FORMATION				(8-9) (60-110)		
LOWER			GRANEROS GROUP	BELLE FOURCHE SHALE		90-70
				MOWRY SHALE		45-75
		NEWCASTLE SANDSTONE			5-20	
		SKULL CREEK SHALE			50-80	
		FALL RIVER (DAKOTA (?) ss)			1-60	
		Fusion Shale			1-57	
		Minnewashta ls			0-8	
		8-148				
		JURASSIC		MORRISON FORMATION		0-67
				UNKPAPA SS		0-70
SUNDANCE FM			Redwater Mem. Lee Member Huett Member Steeple Butte Cannon Bar Mem.	75-140		
GYPSUM SPRING				0-14		
TRIASSIC ?	SPEARFISH FORMATION			75-215		
	Goose Egg Equivalent					
PERMIAN	MINNEKAHTA LIMESTONE		9-15			
	OPECHE FORMATION		15-41			
PENNSYLVANIAN	MINNELUSA FORMATION		110-260			
MISSISSIPPIAN	PAHASAPA (MADISON) LIMESTONE		90-190			
DEVONIAN	ENGLEWOOD LIMESTONE		9-20			
ORDOVICIAN	WHITEWOOD (RED RIVER) FORMATION		0-20			
	WINNIPEG FORMATION		0-30			
CAMBRIAN	DEADWOOD FORMATION		1-120			
PRE-CAMBRIAN	METAMORPHIC and IGNEOUS ROCKS		600			

(MODIFIED AFTER GRIES, 1974)

Formation is 3 to 120 meters (10 to 400 feet) thick. Conformably overlying the Deadwood Formation is the Winnipeg Formation which is a shale unit interbedded with siltstone and sandstone. The Winnipeg Formation is from less than 0.3 to 30 meters (1 to 100 feet) thick. The Whitewood Dolomite conformably overlies the Winnipeg and consists of as much as 20 meters (60 feet) of dolomite in the northern Black Hills. The Englewood Formation, which is a limestone from 9 to 20 meters (30 to 60 feet) thick, grades upward into the overlying Pahasapa Limestone Formation which is a cavernous dolomite from 90 to 190 meters (300 to 630 feet) thick. The Pahasapa Limestone is a prolific water-bearing deposit and can be ore-bearing. The Minnelusa Formation lies unconformably over the Pahasapa Limestone and consists of an alternating series of sandstones and dolomites interbedded with minor amounts of shale and chert. The Minnelusa Formation is between 110 to 260 meters (350 to 850 feet) thick and is a waterbearing formation with numerous springs which emerge from the outcropping sandstones. The Minnelusa is overlain by the Opeche Shale Formation, which is 15 to 40 meters (50 to 135 feet) of red silty shale with discontinuous beds of gypsum or anhydrite.

A relatively thick sequence of Mesozoic sedimentary rocks conformably overlies the Paleozoic section. The Spearfish Formation is 75 to 200 meters (250 to 700 feet) of interbedded red siltstone, shale, and gypsum. Unconformably overlying the Spearfish is the Middle Jurassic (180 million to 135 million years old) Gypsum Spring Formation which consists of interbedded gypsum, siltstone, and shales as much as 38 meters (125 feet) thick. The Sundance Formation lies conformably over the Gypsum Spring and is an alternating unit of sandstone and shale which is 75 to 140 meters (250 to 450 feet) thick. The Unkpapa Sandstone conformably overlies the Sundance and underlies the Morrison Formation. The Unkpapa is a fine-grained sandstone up to 15 meters (45 feet) thick while the Morrison is an interbedded shale and sandstone which reaches thicknesses of 67 meters (220 feet) in some areas. Unconformably overlying the Morrison is the Inyan Kara Group which consists of the Lakota Formation and the Fall River Sandstone. These

formations are important aquifers in the Belle Fourche vicinity. The Fall River Sandstone is conformably overlain by a series of Cretaceous (135 million to 63 million year old) shale and sandstone formations: Skull Creek, Newcastle Sandstone, Belle Fourche, and Mowry Shales; Greenhorn Limestone, Carlile Shale, Niobrara Formation, Pierre Shale, Fox Hills Sandstone, and the Hell Creek Formation. These formations outcrop on the Great Plains, quite far from the study area.

The Oligocene (36 million to 25 million year old) White River Group unconformably overlies the Mesozoic rocks and consists of 10 to 200 meters (0 to 600 feet) of clays with local channel fillings and limestones. Tertiary intrusive rocks are found as dikes, sills, and laccoliths in the northern Black Hills. The composition varies from rhyolites to andesite.

The Quaternary (less than 1 million year old) deposits include alluvial material in streambeds, terrace deposits of gravel, landslide material, and minor deposits of windblown sand. The Quaternary deposits range up to 15 meters (50 feet) in thickness.

Structure

As discussed in the regional geology section, the Paleozoic and Mesozoic sedimentary rocks have been intruded by a series of west-northwest trending stocks, laccoliths, and dikes of Tertiary age. The Tertiary intrusive belt is a well defined belt which crosses the uplift in a westerly direction. The rocks are steeply inclined on the eastern side and gently dipping on the western side of the uplift. The Lead-Deadwood area, at the headwaters of the three watersheds, is one of the major centers of intrusive activity in the northern Black Hills. The igneous intrusives are one of the causes of deformation expressed as doming, monoclines, folding, and vertical faulting within the overlying sedimentary rocks and Precambrian basement.

The Lead-Deadwood area is a dome which is 19 kilometers (12 miles) in the east-west direction and 16 kilometers (10 miles) in the north-south direction and which has approximately 300 meters (1,000 feet) of structural relief. The central core of the dome is Precambrian rocks

surrounded by the Deadwood Formation which dips 5 to 10 degrees from the dome. The intrusives in forms of sills, laccoliths, and dikes intrude the dome. Whitewood Creek flows through the heart of the intrusive activity while Bear Butte Creek flows just to the east and Spearfish Creek flows to the west of the major intrusive activity.

Occurrence of Gold

Gold deposits in the northern Black Hills occur in three forms: syngenetic deposits of Precambrian rocks, replacement deposits in the Tertiary rocks, and placer deposits.

Precambrian Replacement Deposits

Precambrian replacement deposits are syngenetic gold deposits in the Homestake Formation in zones of cross-folding. The Homestake Mine in the Whitewood Creek drainage mines gold from Precambrian replacement deposits and is the largest gold mine in North America.

Tertiary Ore Deposits

Of primary concern to this study are the Tertiary ore deposits because of the potential for economically extracting gold from these deposits by cyanide heap leaching practices. The Tertiary ore deposits are controlled by the orientation and abundance of vertical faults and fractures. These "verticals" served as conduits for the upward movement of hydrothermal fluids. The resultant interaction between these fluids and the wall rock of the Deadwood Formation or the Pahasapa Limestone was a replacement process in which solutions dissolved, altered, and introduced minerals. The ore deposits usually consist of replacement bodies along bedding planes and along the verticals (DeWitt et al., 1986). In the Portland mining district, the vertical system is oriented north-northeast while in the Ruby Basin mining district, they are oriented in a north-northwest system. The ore bodies found at intersections of verticals often are large bodies of high-grade ore.

Ore deposits in the Lead-Deadwood area are formed by replacement along flat channelways and along vertical faults and fractures in the Deadwood Formation and Pahasapa Limestone (Shapiro and Gries, 1970).

Replacement deposits occur in dolomitic horizons localized by high-angle fractures which provide access for ore-forming solutions. The ore deposits occur in the lower and upper contact zones of the Deadwood Formation. The lower contact zone is in contact with the Precambrian rocks (Figure 7). The upper contact zone is 5 meters (15 feet) below the Scolithus Sandstone facies. The replacement ore bodies in both the upper and lower contact zones range from 1 to 6 meters (3 to 20 feet) thick. The deposits are elongated and parallel to the strike of the verticals which are related to major fracture systems. Deposits in the Ruby Basin mining district are in the lower contact zone while deposits in the Portland mining district are in the upper contact zone as well as in the lower contact zone. The replacement deposits are found in the Pahasapa Limestone in the Ragged Top district. The replacements in the Pahasapa Limestone are irregularly shaped lenses and pods.

Two types of ore are found in this area: the primary or blue ores, and the weathered or brown ores. The brown ores have been oxidized so the gold and silver is easily extracted. The primary ores are unoxidized and extraction is more difficult. The blue ores are silicious zones in dolomitic beds of the Deadwood Formation. The ores contain quartz and pyrite with minor amounts of arsenopyrite, sylvanite, and possibly other telluride minerals (Shapiro and Gries, 1970). The secondary ores are primarily a product of the primary ores and a secondary suite of limonite, gypsum, kaolinite, pyrolusite, and minor amounts of wulfenite (Shapiro and Gries, 1970).

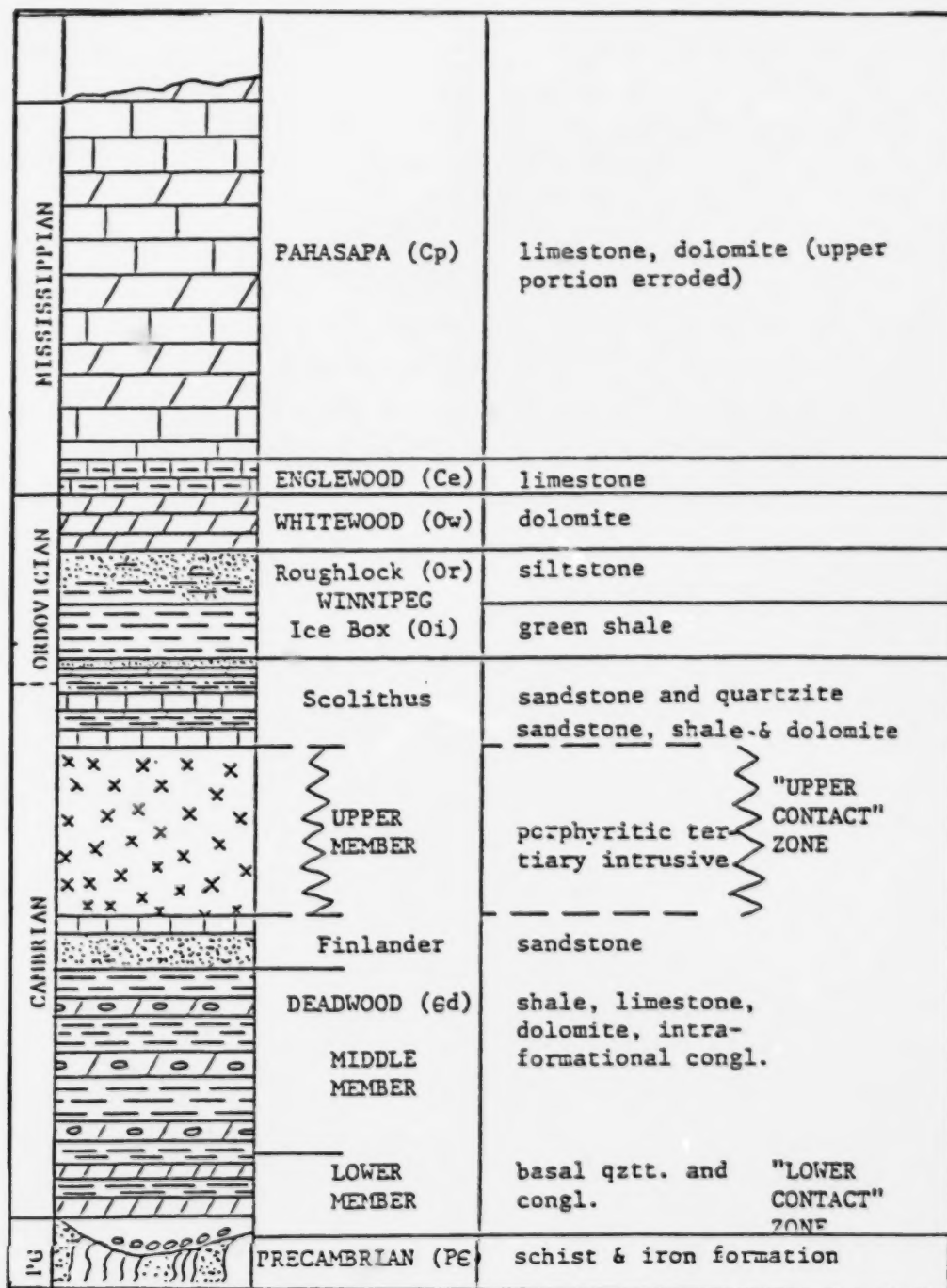
The Pahasapa Limestone deposits consist primarily of randomly oriented and mineralized fractures and massive breccia which have been silicified. The mineralogy of the ore deposits includes silicified masses of Pahapasa Limestone containing quartz, chalcedony, minor auriferous pyrite and some telluride minerals (Shapiro and Gries, 1970).

Placer Deposits

Placer gold deposits in the Black Hills have been found in present-day streambeds, Tertiary gravel deposits, and Cambrian sandstones.

FIGURE 7

STRATIGRAPHIC SECTION SHOWING LOCATION OF UPPER AND LOWER CONTACT ZONE IN DEADWOOD FORMATION



(MODIFIED AFTER KULIK, 1965)

The sources of these placer deposits are the Homestake and Deadwood Formations (Carpenter, 1889). The Whitewood Creek placer deposit is the primary deposit in the study area, although some minor placer deposits occur in both Spearfish and Bear Butte Creeks. The gold is concentrated in gravel beds and lenses ranging from 1 to 6 meters (2 to 20 feet) thick. Most operations to exploit placer deposits have been discontinued because of marginal profits or adverse environmental impacts on the stream (DeWitt et al., 1986).

Ore Deposits Suitable for Heap Leach Processing

As discussed previously, gold occurs in several types of ores in the northern Black Hills. The ore associated with Tertiary intrusives and found in the Paleozoic host rocks is of primary importance. These precious-metal-rich replacement and vein deposits are suitable for heap leaching. The basic criterion for selecting an ore suitable for gold and silver heap-leaching is that sufficient ore with profitable concentrations of gold and silver can be defined. Weathered and oxidized ores are the most suitable for leaching. Ores that contain organic carbon are not suitable for heap-leaching because the carbon prevents much of the gold from dissolving and adsorbs dissolved metals before the leach solutions are recovered. The other requirement is that the ores have a low sulfide content.

Many of the Tertiary replacement gold and silver deposits in the Black Hills are located in the Lead-Deadwood area. Areas of high, medium, and low resource potential for heap-leaching activities are delineated in Figures 8 and 9, where the precious-metal-rich replacement and vein deposits in the Paleozoic rocks are designated as map type "T". A brief description of each area is provided in Table 4. The ore deposits from these types of rocks range from 4 to 9 million metric tons (5 to 10 million short tons) with a gold grade ranging from 1 to 3 grams per metric ton (0.03 to 0.08 troy ounces per short ton).

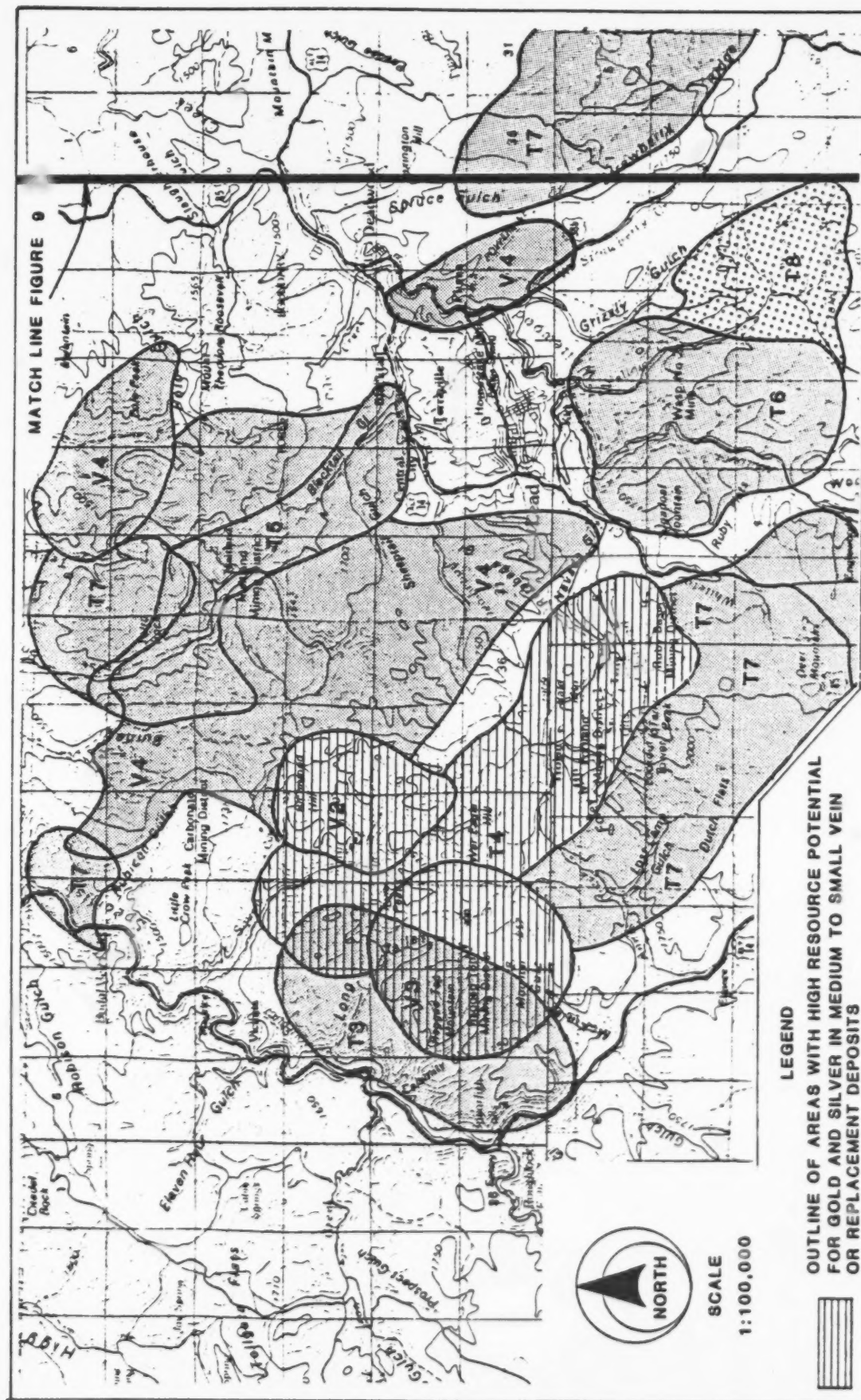


FIGURE 8
MINERAL RESOURCE POTENTIAL FOR THE
NORTHERN BLACK HILLS-SPEARFISH CREEK
AND WHITEWOOD CREEK

(DEWITT et al, 1996)

MAP UNITS (e.g. T3, V2) ARE DESCRIBED IN TABLE 4

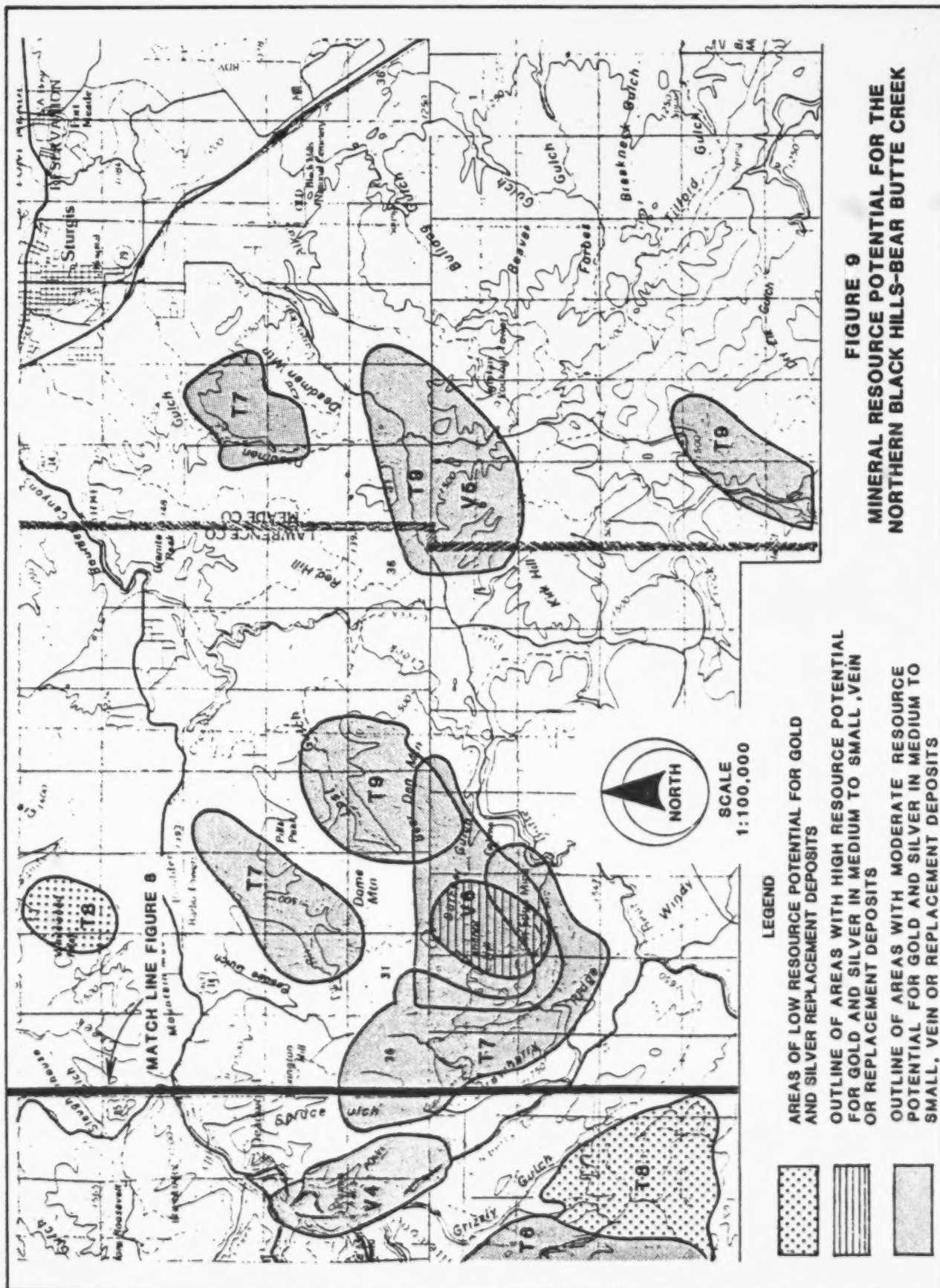


TABLE 4

DESCRIPTION OF GOLD AND SILVER POTENTIAL
IN THE LEAD-DEADWOOD AREA OF THE NORTHERN BLACK HILLS

<u>Map Unit</u>	<u>Description</u>
T3	The deposits in the Ragged Top mining district have moderate potential for precious metals in small vein or replacement deposits in the Pahasapa Limestone and, possibly, the underlying strata. Ores in this area contain the highest ratios of gold to silver in the northern Black Hills.
T4	The deposits in the main portions of the Portland and Ruby Basin mining districts have high resource potential for precious metals in medium-size replacement and vein deposits contained in the Deadwood Formation. The area yielded approximately 44 million grams (1,400,000 troy ounces) of gold and 110 million grams (3,400,000 troy ounces) of silver from 1887 to the late 1960's.
T5	The deposits in the Garden-Maitland district have moderate resource potential for precious metals in small- to medium-size replacement and vein deposits.
T6	Deposits in this area south of Lead, near the Wasp Gold Mine, have moderate potential for precious metals in small- to medium-sized replacement and vein deposits in the Deadwood Formation.
T7	Seven areas have been included in this description area. The deposits all have moderate potential for precious metals in medium- to small-size vein or replacement deposits.
T8	Two small areas in the Lead-Deadwood region have low potential for small vein or replacement deposits in Paleozoic rocks.
T9	Two areas have a moderate potential for precious metals in small vein deposits in Paleozoic rocks. In both areas the Pahasapa Limestone and older Paleozoic strata are in contact with various phases of intrusive bodies creating a favorable geologic setting for vein replacement deposits. No known production exists in these areas.

(Continued)

TABLE 4 (Continued)

<u>Map Unit</u>	<u>Description</u>
V2	This deposit in the Richmond Hill area has high potential for medium-sized disseminated or porphyry deposits containing precious metals and copper. The deposits are placement deposits in the Pahasapa Limestone probably related to one of the stocks in the area.
V3	This deposit in the Ragged Top district has high potential for gold and silver in medium to small disseminated or porphyry deposits. The replacement and vein deposits are in the Pahasapa Limestone.
V4	Several areas are included in this map unit. The areas have moderate potential for small disseminated or porphyry deposits containing gold and silver. The areas contain numerous dikes and irregularly shaped intrusive bodies that range in composition from rhyobite to quartz.
V5	This area centered on the Gilt Edge Mine has moderate potential for precious metals in medium to small disseminated or porphyry deposits.
V6	This area is west of the Galena district and has a high potential for medium-size disseminated or porphyry deposits containing precious metals.
T -	Precious-metal-rich replacement and vein deposits in Paleozoic rocks.
V -	Precious-metal-rich disseminated and vein deposits in Tertiary quartz-normative, subalkalic to alkalic igneous rocks.

Source: Modified from Dewitt et al., 1986.

Another type of deposit suitable for heap-leaching is also associated with the Tertiary intrusives. DeWitt et al. (1986) call them the precious-metal-rich disseminated and vein deposits in Tertiary quartz-normative, subalkalic to alkalic igneous rocks. The deposits are in Tertiary rhyolitic stocks and are designated as map type "V" in Figures 8 and 9 and Table 4. These disseminated or porphyry-type deposits are becoming an increasingly important exploration target because of the low cost of mining the deposits and the ability to use heap-leaching techniques to recover the precious metals. These types of deposits, similar to those at Gilt Edge Mine, probably could produce ore in the next 5 years (DeWitt et al., 1986). These oxidized ores are amenable to heap-leaching.

GROUND WATER HYDROLOGY

In the Black Hills area, numerous water-bearing formations ranging in age from Precambrian to Recent (less than 10,000 years old) have been identified as generally having good water quality (Fox, 1984). The principal water bearing units in the study area in the northern Black Hills are alluvial deposits, sandstone aquifers, and carbonate aquifers.

The alluvial deposits consist of unconsolidated stream channel deposits, including gravels, sands, and silts. They typically range in thickness from 0 to 40 feet or more. The deposits tend to be discontinuous and of limited extent in the northern Black Hills. The aquifers are generally unconfined so the water table fluctuates as the recharge varies with precipitation, irrigation, and streamflow loss. The ground water in alluvial deposits is often transmitted through faults, fractures, and joints to the underlying aquifers (Fox, 1984).

The sandstone aquifers include the Inyan Kara Group (Fall River Sandstone and Lakota Formations), the Sundance Formation, the Minnelusa Formation, and the Deadwood Formation (see Figure 6). The aquifers in the Inyan Kara Group are generally permeable and productive with fair water quality in the vicinity of its outcrop. Elsewhere, the water is often saline. Recharge occurs from precipitation, stream losses, and

by leakage from the shallow alluvial aquifers. The potentiometric surface slopes from the Black Hills uplift toward the southeast and northeast (Todd, 1983). Water quality in the Sundance Formation is often highly mineralized except near its outcrop where it yields less mineralized water that is suitable for domestic use (South Dakota State Geological Survey, 1964). The Minnelusa Formation is predominantly a white and red calcareous sandstone that ranges from 300 to 880 feet thick at its outcrop around the Black Hills. Several irrigation wells in the vicinity obtain good quality water from the Minnelusa Formation. A well penetrating the Minnelusa near Sturgis initially yielded 250 liters per second (4,000 gallons per minute) which later reduced to about 50 liters per second (750 gallons per minute) (South Dakota State Geological Survey, 1964). Aquifers in the Deadwood Formation yield small to moderate amounts of good to saline water suitable for stock and domestic supplies.

There are only a few carbonate limestone and dolomite aquifers, but they generally have a large areal extent and are capable of large yields where cavernous limestones are located. Ground water in limestone or dolomite aquifers occurs in openings that range from small pores, joints, and fractures to large caverns. These fractures and caverns may substantially increase the storage and transmissivities of the aquifer. The Pahasapa Limestone (equivalent to the Madison) is the most prolific of these water-bearing deposits and ranges in thickness from 90 to 200 meters (300 to 650 feet). It is recharged by precipitation, streamflow losses, and by leakage from overlying aquifers. As surface flow encounters the outcropping Pahasapa Limestone in the valley bottoms, the streams lose much of their water to the cavernous limestone. Recharge is estimated to be 170 millimeters (6.8 inches) per year in this area of the Black Hills (Rahn and Gries, 1973). The Whitewood Dolomite outcrops in a narrow band around the Black Hills uplift. The aquifer may furnish water to the overlying Pahasapa aquifer through leakage if large amounts of water are withdrawn from the Pahasapa Limestone (Todd, 1983). The Whitewood Dolomite aquifer contains saline waters and is not used as a source of water.

Springs from these aquifers are also an important water supply. The primary source of the springs is thought to be the Pahasapa Formation and it is believed that faulting or channeling has allowed the water to reach the surface. The numerous springs in the area suggest the possibility of fault zones which would allow artesian water to migrate to the surface along fault planes.

Table 5 summarizes water quality analyses for selected ground water wells in the study area. The wells were sampled by the U.S. Geological Survey (USGS) and are either municipal or domestic wells. Wells 1, 2, and 3, located in the Spearfish Creek Drainage, (Figure 10) are completed in the Pahasapa Limestone and Deadwood Formation. Wells 1 and 2 completed in the Pahasapa Limestone exceed the EPA secondary drinking water criteria for drinking water for manganese. Well 1 also exceeds EPA secondary criteria for sulphate. Well 3, completed in the Deadwood Formation exceeds EPA secondary drinking water criteria for iron and manganese. Wells 4 and 5 are located in the Whitewood Creek Drainage and were sampled in the alluvium and Precambrian aquifers. Chromium levels exceeded the EPA Maximum Contaminant Level (MCL) in well 4 while well 5 did not exceed any of the EPA contaminant levels. In the Bear Butte Creek drainage, one well was sampled in both the Deadwood and Precambrian aquifers. Neither analysis exceeded any of the EPA contaminant levels. The water analyses for wells 2, 3, 5, and 6 indicated a bicarbonate water type. Well 1 was typed as a calcium-, magnesium-, sulfate-rich water.

Spearfish Creek Watershed

Most of the Spearfish Creek watershed in the northern Black Hills is deeply incised through carbonate aquifers. According to records of the South Dakota Department of Water and Natural Resources, the town of Spearfish uses four municipal wells for part of its water supply. Three of the wells are completed in the Pahasapa Limestone between depths of 263 and 329 meters (863 and 1,080 feet). A fourth well is completed in the Minnelusa Formation. The estimated yield for these wells is 0.2 to 0.3 liters per second (3 to 5 gallons per minute) per

TABLE 5
ANALYSES OF SELECTED GROUND WATER WELLS IN
SPEARFISH CREEK, WHITEWOOD CREEK, AND BEAR BUTTE CREEK WATERSHEDS

Parameter	Drinking Water Guidelines (mg/l)	Spearfish Creek Watershed Well No. 1 (mg/l)	Well No. 2 (mg/l)	Well No. 3 (mg/l)	Whitewood Creek Watershed Well No. 4 (mg/l)	Well No. 5 (mg/l)	Bear Butte Creek Watershed Well No. 6 (mg/l)
Aquifer	--	Pahasapa	Pahasapa	Deadwood	Alluvium	Precambrian	Precambrian
Date sampled	--	6/1/79	10/29/82	5/3/77-8/13/81	12/18/81	3/6/58-3/31/81	5/8/79
pH	--	7.30	7.8	7.3-7.5	--	7.5-7.69	8.11
Bicarbonate, HCO ₃	--	453	110	46-89	--	205-246	279
Calcium, Ca	--	139.0	4.4	10.7-42.3	--	54.5-61.7	51.8
Magnesium, Mg	--	72.0	0.4	2.5-9.1	--	7.8-11.9	25.1
Sodium, Na	--	231.0	37.0	2.0-5.5	--	1.7-5.98	1.0
Potassium, K	--	(5.0)	0.60	0.60	--	0.90-1.30	0.6
Chloride, Cl	250 ^{b/}	(15)	(0.8)	(0.4-3)	--	(0-4)	(0.3)
Sulfate, SO ₄	250 ^{b/}	(925) ^{c/}	(5)	(7-12)	(1.87)	(2-10)	(5)
Arsenic, As	0.05 ^{a/}	(0.0005)	--	(0.004-0.005)	(0.029)	(0.001)	(0.08)
Barium, Ba	1 ^{a/}	(0.007)	--	(0.059-0.70)	(0.001)	(0.049-0.069)	--
Boron, B	--	(0.784)	0.02	--	--	--	0.002
Cadmium, Cd	0.01 ^{a/}	--	--	(0.001)	(0.006) ^{c/}	(0.001-0.002)	0.001
Chromium, Cr	0.05 ^{a/}	(0.004)	--	(0.001-0.003)	(0.170) ^{c/}	(0.001-0.01)	--
Cobalt, Co	--	(0.002)	--	--	--	--	0.003
Copper, Cu	1.0 ^{b/}	--	--	--	--	--	0.01
Fluoride, F	1.4-3.4 ^{a/}	(0.002)	--	(0.003-0.045)	--	(0.01)	0.10
Iron, Fe	0.3 ^{b/}	(0.011)	1.9	0.01-0.2	1.87	0.16-0.31	0.01
Lead, Pb	0.05 ^{a/}	0.150	0.150	(0.290-0.690) ^{c/}	(0.007)	(0.02-0.04)	10
Manganese, Mn	0.05 ^{b/}	-- ^{c/}	0.088 ^{c/}	(0.002-0.007) ^{c/}	--	(0.002-0.012)	0.001
Molybdenum, Mo	--	(0.663) ^{c/}	--	--	--	(0.20)	0.01
Nickel, Ni	--	(0.013)	--	--	--	--	0.01
Silver, Ag	0.05 ^{a/}	(0.004)	--	--	(0.001)	--	--
Strontium, Sr	--	(1.911)	--	--	--	(0.001-0.002)	--
Vanadium, V	--	(0.004)	--	--	--	--	0.001
Zinc, Zn	5.0 ^{b/}	(0.090)	0.042	(0.168-2.43)	1.450	(0.77)	0.006
Aluminum, Al	--	(0.010)	--	--	--	--	0.003
Lithium, Li	--	(0.182)	--	--	--	--	0.004
Selenium, Se	0.01 ^{a/}	(0.0004)	--	--	(0.003)	(0.001)	--
Titanium, Ti	--	(0.002)	--	--	--	--	--
Zirconium, Zr	--	(0.002)	--	--	--	--	--
Uranium, U	--	(0.0045)	--	--	--	--	--
Cesium-144 Total (pCi/L)	--	30	--	--	--	--	--
Water Use	--	Domestic	Public	Public	Public	Public	Public

a/ EPA MCL.

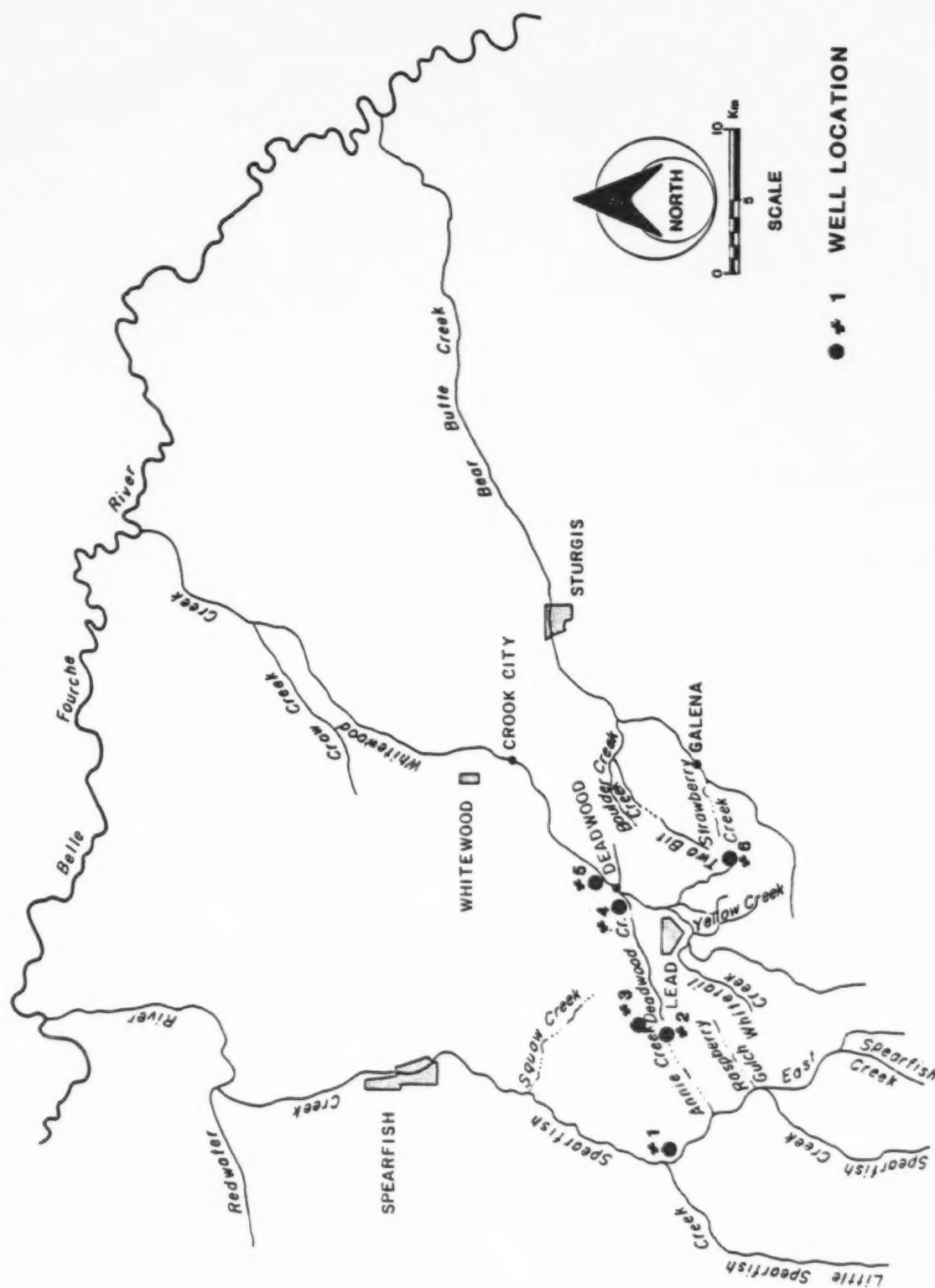
b/ EPA Secondary Criteria (not enforceable).

c/ Samples exceed EPA standards or guidelines.

() Indicates total metals (unfiltered samples); other numbers represent dissolved metals (filtered samples).

Source: EPA STORET Data Base.

**FIGURE 10
SELECTED GROUND WATER
WELL LOCATIONS**



(EPA STORET DATA BASE)

foot of drawdown. Summer residents along Spearfish Creek and the small developed areas near Deer Mountain and Terry Peak Ski Area generally have private ground water wells for domestic use. The Terry Peak Ski Area has one well completed in the Deadwood which it uses for snow-making. Immediately north of Terry Peak an abandoned mine shaft containing water of good quality is used as a community water supply.

Whitewood Creek Drainage

Ground waters in the upper reaches of the Whitewood Creek drainage where the drainage crosses the Precambrian and Cambrian bedrock occur predominantly in shallow alluvial deposits. The Deadwood Formation is also a productive aquifer in this area. Water is supplied to the town of Lead by the Homestake Mining Company from a series of surface springs. The town of Whitewood has two wells completed in the Minnelusa Formation. Diamond Springs and the Cutting Mine Shaft provide municipal water supply for the town of Deadwood, according to records of the South Dakota Department of Water and Natural Resources.

Bear Butte Creek Drainage

The water supply for the town of Sturgis is provided by four wells which are dually completed in the Pahasapa Limestone and the Minnelusa Formation.

SURFACE WATER HYDROLOGY

The northern Black Hills lie in the Belle Fourche River system, which is part of the larger Cheyenne River System. The Cheyenne River between the Belle Fourche River confluence and the Missouri River ranks as one of the State of South Dakota's worst-quality river segments (U.S. Environmental Protection Agency, 1985). Severe suspended solids problems resulting from past mining practices have been traced to soil erosion and mine tailings in the Black Hills. The river has been found to contain high concentrations of sulfate, arsenic, barium, beryllium, chromium, iron, manganese, lead, nickel, and sodium. Many of these

substances are found naturally in the area's shale formations, although some are undoubtedly associated with past mining operations. Water quality has improved considerably since active tailings discharge was discontinued in 1977.

Belle Fourche River

The Belle Fourche River on the Missouri Plateau upstream from the town of Belle Fourche has a drainage basin of 8,420 square kilometers (3,250 square miles) (Darton, 1909). There are three USGS gauging stations on the Belle Fourche River between the town of Belle Fourche and the confluence with Bear Butte Creek (Figure 11). The average annual discharge of the river upstream from the study area at the Wyoming-South Dakota state line is 2.59 cubic meters per second (91.4 cubic feet per second) (cfs) (Table 6). Downstream at Sturgis, the average discharge is 7.90 cubic meters per second (279 cfs) (Hoffman et al., 1984). Periods of high flow occur in May and June and correspond to periods of peak precipitation. Low flow occurs in the late fall and winter months. Water quality in the Belle Fourche River has improved since 1977, largely because Homestake Mine ceased active tailings discharge (Fox Consultants, Inc., 1984). Nonetheless, water quality data collected in 1983 by the U.S. Geological Survey and by Fox Consultants, Inc. (1984) indicate that the Belle Fourche River carries elevated concentrations of sulfate, iron, and manganese derived from both the natural environment and from mine tailings and that EPA secondary drinking water criteria are exceeded for iron and sulfate. Trace concentrations of zinc, nickel, and copper also occur and appear to be derived from the mine tailings (Fox Consultants, Inc., 1984). Recent sampling by the U.S. Geological Survey (Hoffman et al., 1984) indicated that total cyanide was detectable in the Belle Fourche River at concentrations ranging from 0.02 to 0.33 milligrams per liter (mg/l) during March, April, and May of 1984 but were below detection (less than 0.01 mg/l) during the remainder of 1984. These measurements were made prior to the construction of Homestake's cyanide treatment facility (F.D. Fox, Homestake Mining Company, personal communication, 1986). A portion of the Belle Fourche River and a tributary (Whitewood Creek)

FIGURE 11
SURFACE WATER RESOURCES

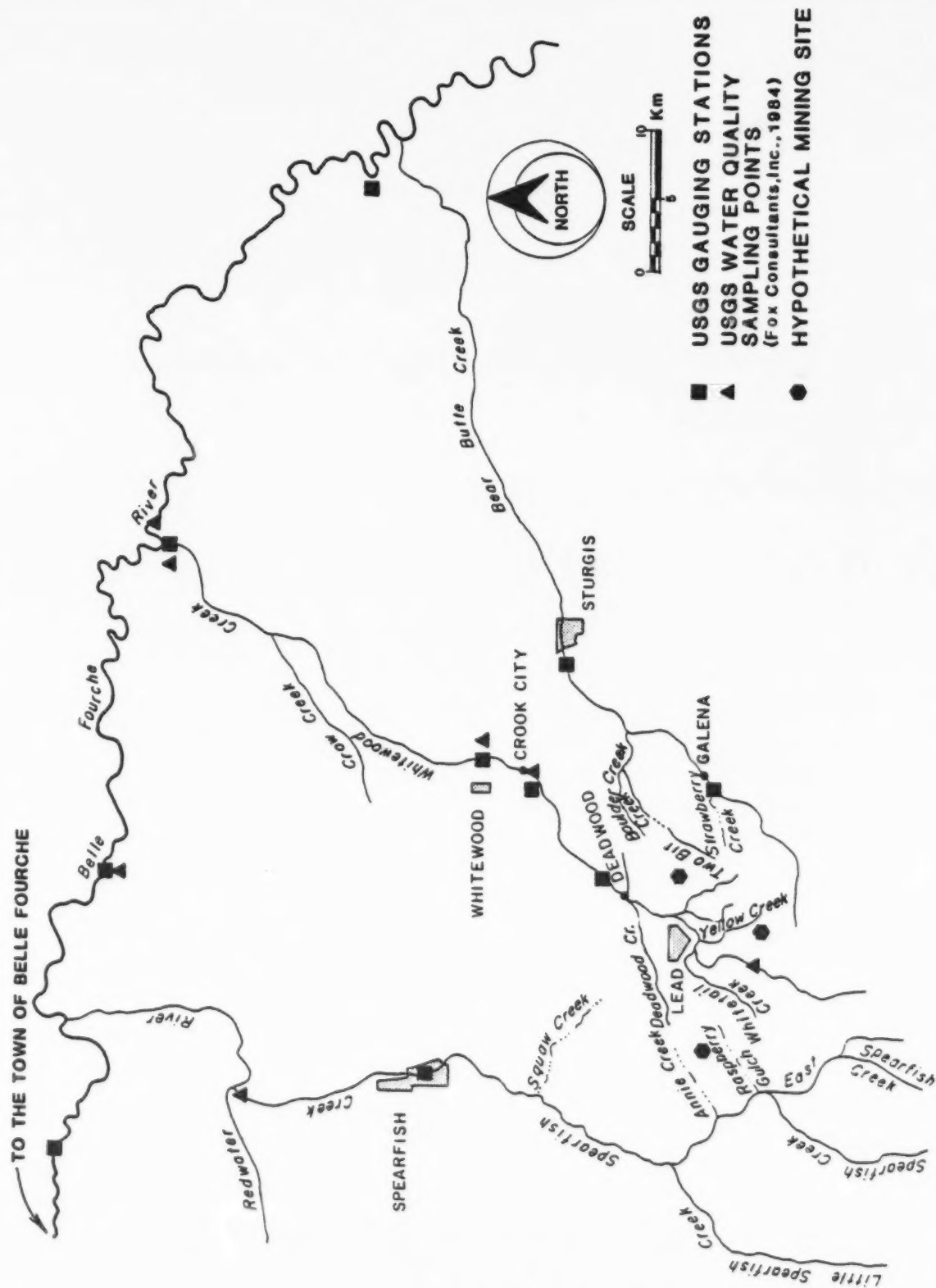


TABLE 6
FLOW RATES OF SELECTED STREAMS IN THE NORTHERN BLACK HILLS

	Mean Monthly Discharge in m^3/s (cfs in parenthesis)												Maximum Instantaneous Discharge	Minimum Instantaneous Discharge
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.		
Spearfish Creek at Spearfish	1.79 (63.3)	1.52 (53.6)	1.17 (41.2)	1.60 (56.4)	1.40 (49.6)	1.64 (57.8)	1.98 (69.9)	3.00 (106)	4.02 (142)	1.92 (67.8)	1.71 (60.3)	1.32 (46.5)	120 (4,240)	b/
Whitehead Creek at Deadwood	0.470 (16.6)	0.391 (13.8)	0.251 (8.88)	0.374 (13.2)	0.351 (12.4)	0.521 (18.4)	1.13 (40.0)	6.03 (213)	2.89 (102)	0.833 (29.4)	0.541 (19.1)	0.416 (14.7)	75.3 (2,660)	b/ c/
Whitehead Creek above Whitehead	0.552 (19.5)	0.456 (16.1)	0.292 (10.3)	0.337 (11.9)	0.396 (14.0)	0.580 (20.5)	1.20 (42.4)	3.65 (129)	2.86 (101)	0.883 (31.2)	0.500 (17.5)	0.416 (14.7)	19.4 (684)	d/
Whitehead Creek near Whitehead	0.625 (22.1)	0.566 (20.0)	0.328 (11.6)	0.405 (14.3)	0.473 (16.7)	0.626 (22.1)	1.38 (48.9)	3.82 (135)	2.38 (84.2)	0.912 (32.2)	0.524 (18.5)	0.433 (15.3)	86.3 (3,050)	c/
Whitehead Creek above Vale	0.801 (28.3)	0.462 (16.3)	0.326 (11.5)	0.450 (15.9)	0.569 (20.1)	0.861 (30.4)	1.45 (51.1)	4.25 (150)	4.42 (156)	0.994 (35.1)	0.513 (18.1)	0.323 (11.4)	30.3 (1,070)	d/
Bear Butte Creek at Galena	h/	ND	ND	ND	ND	ND	0.527 (18.6)	0.82 (29.0)	0.031 (1.79)	0.034 (1.20)	ND	ND	538 (19,000)	f/
Bear Butte Creek at Sturgis	0.118 (4.15)	0.176 (6.23)	0.154 (5.43)	0.142 (5.02)	0.453 (16.0)	0.303 (10.7)	0.345 (12.2)	1.28 (45.2)	6.40 (226)	0.634 (22.4)	0.174 (6.15)	0.069 (2.42)	204 (7,220)	k/
Belle Fourche River at Wyoming State Line	0.722 (25.5)	0.614 (21.7)	0.317 (11.2)	0.518 (18.3)	0.883 (31.2)	4.05 (143)	2.57 (90.7)	10.1 (355)	23.0 (812)	3.09 (109)	1.25 (44.1)	0.580 (20.5)	125 (4,400)	b/
Belle Fourche River near Fruitdale	0.177 (6.26)	0.171 (6.05)	0.112 (3.97)	0.117 (4.14)	0.092 (3.25)	0.107 (3.77)	0.107 (3.77)	8.58 (303)	27.6 (974)	0.479 (16.9)	0.294 (10.4)	0.244 (8.62)	360 (12,700)	e/
Belle Fourche River near Sturgis	2.27 (80.1)	1.52 (53.8)	0.629 (22.2)	0.603 (21.3)	1.79 (63.2)	1.75 (61.9)	2.59 (91.4)	28.1 (992)	63.0 (2,225)	10.7 (377)	10.1 (356)	9.12 (322)	1,030 (36,400)	e/

a/ From Hoffman et al., 1984

b/ Period of Record: 38 years

c/ Period of Record: 3 years

d/ Period of Record: 2 years

e/ Period of Record: 39 years

f/ From U.S. Geological Survey, 1972

g/ From U.S. Geological Survey, 1969

h/ ND - No Data

i/ Schwarz et al., 1975

j/ Period of Record: 4 years

k/ Period of Record: 27 years

l/ Period of Record: 1 year

were placed on the National Priorities List for evaluation under CERCLA because of water quality degradation resulting from past mining activities.

The beneficial uses designated by the State of South Dakota for the Belle Fourche River from the Wyoming border to the Cheyenne River are warm water permanent fish life propagation, immersion recreation, and limited contact recreation. In addition, all of the State's waters are designed as suitable for wildlife propagation and stock watering, and irrigation (see Table 7 for a list of criteria used to determine suitable uses).

All three streams which were evaluated for impacts from potential cyanide heap leach operations are tributary to the Belle Fourche River. Spearfish Creek empties into the Redwater River, which flows into the Belle Fourche approximately 260 kilometers (160 miles) upstream from its confluence with the Cheyenne River. Whitewood and Bear Butte Creeks both empty directly into the Belle Fourche approximately 210 and 160 kilometers (130 and 100 miles), respectively, upstream from the confluence of the Belle Fourche River with the Cheyenne River.

Spearfish Creek Watershed

Spearfish Creek originates in the Black Hills at an elevation of about 2,000 meters (6,500 feet) and flows 56 kilometers (35 miles) northeast past the town of Spearfish before joining the Redwater River at an elevation of 1,000 meters (3,300 feet). The larger Redwater River flows another 16 kilometers (10 miles) across the Belle Fourche River flood plains before joining the Belle Fourche River just upstream from the town of Belle Fourche.

Spearfish Creek drains part of a high limestone plateau and its adjacent slopes in the northern Black Hills. This 12,000-hectare (30,000-acre) drainage basin is the largest of the three streams chosen for study in this project. Its principal tributary is Little Spearfish Creek, which carries about one-tenth the flow of Spearfish Creek. Spearfish Creek itself is the largest tributary to the Redwater River and has an average annual discharge over a 38-year period of 1.5 cubic

TABLE 7
STATE OF SOUTH DAKOTA
SURFACE WATER QUALITY STANDARDS
FOR STREAMS IN THE BLACK HILLS STUDY AREA^{a/}

Parameter	1	2	3	4	5	6	7	8	9	10	11
	Domestic water supply	Cold water permanent fish life propagation	Cold water marginal fish life propagation	Warm water permanent fish life propagation	Warm water semi- permanent fish life propagation	Warm water marginal fish life propagation	Immersion recreation	Limited contact recreation	Wildlife propagation and stock watering	Irrigation waters (May 15 - Sept. 30)	Commerce and Industry
Alkalinity, Total/CaCP ₃	---	---	---	---	---	---	---	---	---	---	---
Arsenic	.05	---	---	---	---	---	---	---	---	---	---
Barium	1.0	---	---	---	---	---	---	---	---	---	---
Cadaluim	0.01	---	---	---	---	---	---	---	---	---	---
Chloride	250	100	---	---	---	---	---	---	---	---	---
Chlorine, Total Residual	---	.02	.02	.02	.02	---	---	---	---	---	---
Chromium	.05	---	---	---	---	---	---	---	---	---	---
Coliform/100ml	5000	---	---	---	---	---	200	1000	---	---	---
Coliform Fecal/100ml	---	---	---	---	---	---	---	---	---	---	---
Conductivity micromhos/cm @ 25°C	---	---	---	---	---	---	---	---	---	---	---
Cyanide, Free	---	.005	.005	.005	.005	---	---	---	4000	2500	---
Cyanide, Total	---	.02	.02	.02	.02	---	---	---	---	---	---
Hydrogen Sulfide	---	.002	.002	.002	.002	---	---	---	---	---	---
Lead	.05	---	---	---	---	---	---	---	---	---	---
Mercury	.002	---	---	---	---	---	---	---	---	---	---
Nitrogen, Nitrates as N	10	---	---	---	---	---	---	---	50	---	---
Nitrogen, Ammonia as N	---	.02	.02	.04	.04	---	---	---	---	---	---
Oxygen, Dissolved	---	6.0	5.0	5.0	5.0	---	5.0	5.0	---	---	---
DO - in spawning area	---	7.0	---	6.0	---	---	---	---	---	---	---
pH (standard units)	6-9	6.6- 8.6	6.5- 8.5	6.5- 9.0	6.3- 9.0	---	5.5- 8.3	6-9	6.0 9.5	---	---
Polychlorinated biphenyls	---	.000001	.000001	.000001	.000001	.000001	---	---	---	---	---
Selenium	.01	---	---	---	---	---	---	---	---	---	---
Sodium, absorption ratio	---	---	---	---	---	---	---	---	---	---	---
Solids, suspended	---	30	90	90	90	---	---	---	---	10	---
Solids, Total Dissolved	1000	---	---	---	---	---	---	---	2500	---	---
Sulfate	500	---	---	---	---	---	---	---	---	---	---
Temperature (°C)	---	18	24	27	32	---	---	---	---	---	---
Temperature (°F)	---	65	75	80	90	---	---	---	---	---	---

^{a/} All units in mg/l unless otherwise indicated.

Source: Article 74:03 Water Pollution Program, State of South Dakota.

meters per second (53.1 cfs) at the USGS gauging station at Spearfish (see Table 6). The maximum recorded discharge at Spearfish of 120 cubic meters per second (4,240 cfs) occurred on May 15, 1965. Historically, yearly peak flows occur in May and June in response to high precipitation, with low flows occurring in late fall and winter. Average yearly water yield is about 4.4 million cubic meters (36,000 acre-feet) (U.S. Forest Service, 1976). A considerable reduction in flow occurs in Spearfish Creek about 5 kilometers (3 miles) upstream from the town of Spearfish. The stream in this segment was completely dry during a 1986 site visit by the authors in July of 1986. Much of the flow is diverted by the Homestake Mining Company and used for power generation. However, even when the water was not diverted, most of the water flowed underground into the limestone outcrops in the area. Flow resumes immediately upstream from the fish hatchery near the town of Spearfish.

Water in Spearfish Creek is of the calcium carbonate type and is moderately alkaline (U.S. Geological Survey, 1983). Trace metal concentrations are generally below detection and cyanide was not detected in either sediment or water samples (Table 8) (U.S. Geological Survey, 1983). Previous water quality studies available in the EPA STORET data base indicate that there have been periods of decreased water quality. Some mining has historically occurred in the Spearfish Creek drainage.

Beneficial use designations have been made by the State of South Dakota based on the ability of the stream to support communities of aquatic organisms, the quantity or quality of the water, and uses made of the water. Suitable uses on Spearfish Creek as designated by the State of South Dakota are domestic water supply, cold water permanent fish life propagation, immersion recreation, and limited contact recreation, except in the reach of the power plant diversion where the use designation is for cold water marginal fish life propagation and limited contact recreation.

Approximately 8.50 cubic meters per second (300 cfs) in surface water rights have been claimed for power, fish culture, municipal, irrigation, and commercial use according to records of the South Dakota

TABLE 8
SUMMARY OF WATER QUALITY AND SEDIMENT DATA FOR
SPEARFISH CREEK

	Water		Sediment (mg/kg)
	Dissolved (mg/l)	Total (mg/l)	
EC (umhos per cm)	710	--	--
pH (standard units)	8.2	--	--
Calcium	100	110	107,000
Magnesium	36	1.8	12,300
Sodium	5.0	6.8	560
Potassium	1.5	38	750
Alkalinity	233	--	--
Sulfate	150	--	--
Chloride	7.2	--	--
Arsenic	<0.010 ^{a/}	<0.010	11
Cadmium	<0.001	<0.001	<1
Chromium	<0.010	<0.010	3
Copper	<0.050	<0.050	3
Iron	<0.050	0.074	2,600
Lead	<0.005	<0.005	8
Manganese	<0.012	<0.010	180
Mercury	<0.0002	<0.0002	<0.10
Nickel	<0.040	<0.040	4
Selenium	<0.020	<0.020	<1
Silver	<0.010	<0.010	<1
Zinc	<0.010	<0.010	9
Cyanide	<0.00001	<0.00001	<1

a/ Indicates the concentration was below the detection limit for this substance.

Source: U.S. Geological Survey, 1983. Station located near the confluence with the Redwater River. Samples collected 7-15-83.

Department of Water and Natural Resources. The Homestake Mining Company is a primary user of surface water in the Spearfish Creek drainage and diverts water for power generation and mining, and supplies treated water for municipal use to the town of Lead and a portion of Deadwood. The town of Spearfish diverts water from Spearfish Creek for municipal use in addition to water supplied from deep water wells. (See the discussion in the ground water section.) Upstream from the town of Spearfish, the fish hatchery has water rights on Spearfish Creek. Further downstream on the plains north of the Black Hills, Spearfish Creek is used primarily for irrigation.

The site chosen for the hypothetical mining operation is located in the headwaters of Raspberry Gulch (see Figure 11). The gulch is ephemeral, flowing only in response to snowmelt and precipitation events. Raspberry Gulch is located in steep terrain with its origin at an elevation of about 1,800 meters (6,000 feet). Its slope is about 10 percent over its 2.4 kilometer (1.5-mile) course. Water quality data in the gulch is lacking, but is expected to be of high quality except for minor amounts of suspended sediment. No water rights were identified for these gulches.

Whitewood Creek Watershed

Whitewood Creek is a tributary of the Belle Fourche River, flowing northeast from its source in the Black Hills past the Homestake Mine and the towns of Lead, Deadwood, and Whitewood before emerging onto the flood plain of the Belle Fourche River on the Missouri Plateau. The majority of the flow in Whitewood Creek during low flow periods, originates as effluent from the Homestake Mine. Its headwaters are located at an elevation of 1,900 meters (6,200 feet) and the creek flows about 50 kilometers (30 miles) before entering the Belle Fourche River at an elevation of 4,500 kilometers (2,800 feet).

Whitewood Creek is a stream of moderate volume draining 5,700 hectares (14,000 acres) in a long narrow basin in the Black Hills. From upstream to downstream, there are four USGS gauging stations: at Deadwood, above Whitewood, near Whitewood, and above Vale. These

stations have only been in operation for 2 or 3 years. From upstream to downstream, the recorded average annual discharges for 1984 were 1.2 cubic meters per second (42.0 cfs), 1.01 cubic meters per second (35.7 cfs), 1.04 cubic meters per second (36.8 cfs), and 1.28 cubic meters per second (45.3 cfs) (see Table 6). Average annual water yield is about 4.3 million cubic meters (3,500 acre-feet) (U.S. Forest Service, 1976). In addition to natural flows, Whitewood Creek receives treated water from the gold mine at Lead, which is supplied in part by an aqueduct from Spearfish Creek. Average monthly flows for the period of record were highest in May and June in response to precipitation. Flow averaged 6.03 cubic meters per second (213 cfs) in Deadwood and decreased to an average of 4.42 cubic meters per second (156 cfs) at the mouth (Hoffman et al., 1984). The flow decrease in this reach is due to both water withdrawals and losses to the groundwater. Low flows occurred in the winter months and averaged about 0.28 cubic meters per second (10 cfs).

Tailings have been deposited in Whitewood Creek for about 100 years until 1977. Prior to the initiation of tailings discharge, Whitewood Creek was a small stream with insufficient capacity to move large quantities of sediment. In adjustment to the introduction of vast tonnages of tailings sediments into the stream, the length of the stream channel diminished, primarily through meander abandonment, thereby increasing the stream gradient and thus the stream sediment carrying capacity. As the meanders were being abandoned, the stream began a period of down-cutting. However, this was limited by resistant coarse alluvial deposits and shale outcrops that form the stream bed. As a result, Whitewood Creek became a braided channel characterized by shifting small bars and small unstable islands. The tailings deposits are up to 5 meters (15 feet) thick. It has been speculated (Fox Consultants, Inc., 1984) that the creek is at least partially sealed off from the underlying aquifer by tailings. Whitewood Creek is one of the few streams flowing out of the Black Hills that does not become

intermittent upon crossing the Paleozoic outcrop belt. In the late 1800's, sink holes were plugged to inhibit leakage to the ground water (P. Greese, South Dakota School of Mines, personal communication, 1986).

Whitewood Creek is generally slightly alkaline and of a calcium carbonate type. Results of the USGS sampling program in 1983 (Fox Consultants, Inc., 1984) indicate that the mine tailings along Whitewood Creek have introduced trace elements into surface waters (Table 9). Except for sulfate, no parameters were found in concentrations in excess of recommended water quality criteria for livestock and irrigation. However, EPA drinking water standards and aquatic life standards were exceeded in some samples for arsenic, cadmium, chromium, iron, lead, manganese, mercury, and cyanide. Although cyanide was not detected in every sample, sediment sampling data indicated that cyanide was present at a level of 1 to 2 milligrams per kilogram (mg/kg). Although water quality has improved considerably since the cessation in 1977 of tailings disposal in the creek, water quality has not improved to the levels observed in the less-disturbed Spearfish Creek.

Whitewood Creek has been classified by the South Dakota Department of Water and Natural Resources into four separate beneficial use categories. The segment from its confluence with the Belle Fourche River to Interstate 90 has been designated a warm water, semipermanent fish life propagation and limited contact recreation stream. The semipermanent fish life designation could be due to periodic low flows caused by irrigation withdrawals on the plains during the summer months. The segment of Whitewood Creek upstream from Interstate 90 to Gold Run Creek has been designated as a cold water, marginal fish life propagation, immersion and limited contact recreation stream. The segment from Gold Run Creek to Lead has been designated for cold water permanent fish life propagation, immersion recreation and limited contact recreation. Above Lead, the stream is designated for cold water permanent fish life propagation and limited contact recreation.

TABLE 9

SUMMARY OF WATER QUALITY AND SEDIMENT DATA FOR WHITEWOOD CREEK

	Whitewood Creek Above Lead	Whitewood Creek Above Whitewood	Whitewood Creek Near Whitewood	Whitewood Creek Above Vale
Flow m ³ /s (cfs)	--	0.40-12.1 (14-426)	0.34-7.62 (12-269)	--
pH (standard units)	--	7.1-9.3	6.7-8.7	--
EC (umhos per cm)	--	190-932	388-1100	8.1 (lab) 1320 (lab)
Calcium				
dissolved (mg/l)	--	26-120	47-150	150
total (mg/l)	--	36-150	57-150	180
sediment (mg/kg)	--	19,900	21,200	28,400
Magnesium				
dissolved (mg/l)	--	8.2-54	16-57	63
total (mg/l)	--	13-60	19-56	80
sediment (mg/kg)	--	3,800	3,600	2,800
Sodium				
dissolved (mg/l)	--	3.8-54	14-49	60
total (mg/l)	--	4.8-60	12-53	71
sediment (mg/kg)	--	330	240	270
Potassium				
dissolved (mg/l)	--	1.9-13	3.4-11	12
total (mg/l)	--	3.3-35	4.1-11	14
sediment (mg/kg)	--	890	850	760
Alkalinity (mg/l)	--	85-274	105-186	181
Sulfate (mg/l)	--	17-380	90-510	540
Chloride (mg/l)	--	<3-34	6.0-20	14
Arsenic				
dissolved (mg/l)	<0.010	<10-27	0.011-0.062	0.056
total (mg/l)	<0.001-0.047	0.036-1.400	0.038-0.058	0.120
sediment (mg/kg)	--	650	900	360
Cadmium				
dissolved (mg/l)	<0.010	<0.001-0.007	<0.001-0.005	<0.001
total (mg/l)	<0.010	<0.001-0.025	<0.001-0.009	0.002
sediment (mg/kg)	--	5	6	3

(Continued)

TABLE 9 (Continued)

	Whitewood Creek Above Lead	Whitewood Creek Above Whitewood	Whitewood Creek Near Whitewood	Whitewood Creek Above Vale
Chromium				
dissolved (mg/l)	<0.010	<0.010	<0.010	<0.010
total (mg/l)	<0.010-0.064	<0.010-0.480	<0.010-0.016	<0.010
sediment (mg/kg)	--	4	3	4
Copper				
dissolved (mg/l)	<0.050	<0.050-0.073	<0.050-0.110	<0.050
total (mg/l)	<0.050	<0.050-1.100	<0.050-0.200	<0.050
sediment (mg/kg)	--	99	67	130
Iron				
dissolved (mg/l)	<0.050-0.350	<0.050-0.067	<0.050-0.088	<0.050
total (mg/l)	<0.050-5.9	0.880-202	0.500-13.200	1.200
sediment (mg/kg)	--	28,500	25,800	18,400
Lead				
dissolved (mg/l)	<0.050	<0.005-0.008	<0.005-0.050	<0.005
total (mg/l)	<0.050	<0.005-2.700	<0.005-0.056	<0.005
sediment (mg/kg)	--	18	18	17
Manganese				
dissolved (mg/l)	<0.010-0.020	0.054-0.750	0.052-0.250	0.240
total (mg/l)	<0.010-0.405	0.170-6.700	0.110-0.700	0.320
sediment (mg/kg)	--	730	610	740
Mercury				
dissolved (mg/l)	<0.0002-0.0014	<0.0002	<0.0002	<0.0002
total (mg/l)	<0.0002-0.018	<0.0002-0.011	<0.0002-0.0005	<0.0002
sediment (mg/kg)	--	0.22	0.24	0.42
Nickel				
dissolved (mg/l)	<0.040	<0.040	<0.040	<0.040
total (mg/l)	<0.040	<0.040-0.140	<0.040	<0.040
sediment (mg/kg)	--	17	11	14

(Continued)

TABLE 9 (Continued)

	Whitewood Creek Above Lead	Whitewood Creek Above Whitewood	Whitewood Creek Near Whitewood	Whitewood Creek Above Vale
Selenium				
dissolved (mg/l)	<0.020	<0.002	<0.002-0.007	<0.020
total (mg/l)	<0.020	<0.002-0.048	<0.002-0.004	<0.020
sediment (mg/kg)	--	<1	<1	<1
Silver				
dissolved (mg/l)	<0.010	<0.010	<0.010	<0.010
total (mg/l)	<0.010	<0.010-0.056	<0.010	<0.010
sediment (mg/kg)	--	<1	<1	<1
Zinc				
dissolved (mg/l)	<0.010	<0.010	<0.010	<0.010
total (mg/l)	<0.010-0.040	0.024-4.000	<0.010-0.095	0.018
sediment (mg/kg)	--	100	66	100
Cyanide				
dissolved (mg/l)	<0.010	<0.01-0.24	<0.01-0.15	<0.01
total (mg/l)	<0.010	0.02-0.37	<0.01-0.22	<0.01
sediment (mg/kg)	--	2	1	1

Source: U.S. Geological Survey, 1983; Fox Consultants, Inc., 1984.

Currently, there are about 14 cubic meters per second (500 cfs) claimed in surface water rights on Whitewood Creek, according to records of the South Dakota Department of Water and Natural Resources. Uses for which these water rights were obtained include mining (for the Homestake Mining Company) and irrigation on the plains north of the Black Hills. The majority of the water rights in this watershed are for irrigation. No use of Whitewood Creek for municipal purposes was identified.

The site chosen for the hypothetical mining operation is located in the headwaters of Yellow Creek, a tributary to Whitewood Creek located near Lead (see Figure 11). Yellow Creek originates at an elevation of about 1,800 meters (5,800 feet) and traverses about 4 kilometers (2.5 miles) with a slope of about 5 percent. Although Yellow Creek is perennial, it probably has a small base flow with the highest flows occurring in response to precipitation. No water quality data are available for Yellow Creek. However, since Yellow Creek was the site of a large mining operation during the early 1900's, water quality may exhibit slightly elevated concentrations of suspended solids and trace metals.

Bear Butte Creek Watershed

Bear Butte Creek has a drainage area of 15,000 hectares (37,050 acres) (U.S. Forest Service, 1976). It originates at an elevation of about 1,800 meters (6,000 feet) in the Black Hills, flows past the town of Sturgis at the edge of Black Hills, and empties into the Belle Fourche River at an elevation of about 790 meters (2,600 feet). It is about 60 kilometers (40 miles) in length. West of Sturgis, flow in Bear Butte Creek sinks into the Pahasapa Limestone. Flow then emerges near Sturgis and continues to the mouth. The only two USGS gauging stations on Bear Butte Creek, near Galena and at Sturgis, have been discontinued. However, the recorded yearly average at Sturgis over a 27-year period was 0.379 cubic meters per second (13.4 cfs) (see Table 6). The discharge of 540 cubic meters per second (19,000 cfs) at Galena during the 1972 flood exceeded the 100-year flood (Schwarz et al., 1975). Near Sturgis, the discharge during the 1972 flood was 204

cubic meters per second (7,220 cfs) which was equivalent to a 40-year flood (Schwarz et al., 1975). Peak annual flows generally occur in May and June in response to precipitation events. There are occasional periods of no flow which generally occur in late fall and winter months (U.S. Geological Survey, 1972). Average annual yield from Bear Butte Creek is about 2.7 million cubic meters (2,223 acre-feet) (U.S. Forest Service, 1976).

Water quality data on Bear Butte Creek are limited. The EPA STORET Data Base contains limited water quality data on Bear Butte Creek near Sturgis and above Boulder Creek (see Table 10). The analyses near Sturgis were performed from April 1960 thru May 1962 on several parameters. Of the parameters analyzed, only sulfate exceeded the EPA drinking water standards. At the Bear Butte Creek station above Boulder Creek, pH, conductivity, dissolved oxygen, and alkalinity were the only parameters analyzed.

More recent data collected in conjunction with the Gilt Edge Mine Project indicate that the slightly acidic water is generally of good quality, although some adverse impacts result from a number of abandoned mine workings, waste dumps, and tailings piles in the drainage. Arsenic and copper are slightly elevated although levels are still below criteria recommended for aquatic biota. Iron was also elevated and exceeded levels recommended for aquatic biota. Cyanide was below detection limits. South Dakota has designated the segment from the confluence with the Belle Fourche River to Highway 385 as suitable for cold water marginal fish life propagation and limited contact recreation. Upstream from Highway 385, the use designation improves to cold water permanent fish life propagation and limited contact recreation.

About 25 cubic meters per second (870 cfs) on Bear Butte Creek are claimed in surface water rights for irrigation, recreation, fish culture, municipal use, and milling according to records of the South Dakota Department of Water and Natural Resources. Most of this water is diverted in Meade County, located on the plains north of the Black Hills. An additional 14 cubic meters per second (500 cfs) are claimed on tributaries to Bear Butte Creek, including 11 cubic meters per

TABLE 10

SUMMARY OF WATER QUALITY DATA FOR BEAR BUTTE CREEK
(Data in mg/l unless otherwise indicated)

	Bear Butte Creek ab. Boulder Cr. a/		Bear Butte Creek nr. Sturgis b/		Bear Butte Creek at Mouth c/	
	Dissolved	Total	Dissolved	Total	Dissolved	Sediment
Flow (m ³ /s) (cfs)	--	0.0003-1 0.01-40 106-1690	--	0.003-2.8 0.1-99 817-1600	0.008 3 2020-2120	--
EC (umhos per cm)	--	--	--	--	--	--
pH (standard units)	--	--	--	--	--	8.2-8.3
Calcium	--	--	7.1-8.8	--	7.0-7.5	--
Magnesium	--	--	110-244	--	285-294	--
Sodium	--	--	29-70	--	105-107	--
Potassium	--	--	20-55	--	138-147	--
Alkalinity	--	--	6.4-8.3	--	5.40-7.07	--
Sulfate	--	38-272	--	392-876	--	--
Chloride	--	--	--	319-760	--	--
Arsenic	--	--	--	0.7-13	--	--
Cadmium	--	--	--	--	0.002	--
Chromium	--	--	--	--	0.010	80
Copper	--	--	--	--	0.004-0.010	--
Iron	--	--	--	--	0.050	--
Lead	--	--	--	0.04-0.12	0.002-0.050	--
Manganese	--	--	--	--	0.002	--
Mercury	--	--	--	0.17-0.21	0.271-0.650	--
Nickel	--	--	--	--	0.050	--
Selenium	--	--	--	--	0.015-0.025	--
Silver	--	--	--	--	0.0002	--
Zinc	--	--	--	--	0.040-0.150	--
Cyanide	--	--	--	--	0.003-0.010	--
	--	--	--	--	0.003-0.010	--
	--	--	--	--	0.010	--
	--	--	--	--	0.010	--

a/ Samples analyzed from September 1969 and May 1973.

b/ Samples analyzed from April 1960 to May 1962.

c/ Samples analyzed from February 1984 to April 1984.

Source: EPA STORET Data Base.

second (400 cfs) from Spring Creek. Although Spring Creek is a tributary to Bear Butte Creek, it enters Bear Butte Creek near the confluence with the Belle Fourche River and originates at the foot of the Black Hills rather than in them. No municipal use of Bear Butte Creek was identified.

The site chosen for the hypothetical mining operation is located in the Two Bit Creek drainage. This area is relatively flat, is boggy in the spring during high runoff, and has a number of small beaver dams. Its headwaters are at an elevation 1,700 meters (5,600 feet) and the drainages traverses about 10 kilometers (6 miles) before joining with Boulder Creek and emptying into Bear Butte Creek above Boulder Canyon (see Figure 11). Water quality is generally good according to recent sampling conducted in conjunction with the Gilt Edge Mine. Water was slightly acidic. Free cyanide was generally below detection although one sample was recorded at 0.021 mg/l. Lead, mercury and iron were slightly elevated. No existing water rights were identified in Two Bit Creek.

SOILS

General Soil Characteristics and Resource Uses

Soils in the Black Hills study area vary widely in physical characteristics. Loamy, moderately deep soils occur mainly in the central portions and the foothill sections of the Black Hills. Deeper soils occur in drainage bottoms (U.S. Forest Service, 1983a). The majority of the soils along the slopes in the three drainages are derived from calcareous sandstones, limestones, and soft shales. Drainageway soils were formed from alluvial sediments. Thirteen general soil associations occur among the three drainages from their headwaters to the confluence with the Belle Fourche River. Table 11 depicts the soil associations present in the Spearfish, Whitewood, and Bear Butte Creek drainages. The principal upland associations in the three drainages include the Citadel-Vanocker-Grizzly and Stovho-Trebor-Rock Outcrop associations. The Barnum-Swint-St. Onge and Lohmiller-Glenberg-Haverson associations are predominant in the drainage bottoms.

TABLE 11
SOIL ASSOCIATIONS OCCURRING IN THE
SPEARFISH, WHITEWOOD, AND BEAR BUTTE CREEK
WATERSHEDS OF THE NORTHERN BLACK HILLS

<u>SOIL ASSOCIATION</u>	<u>WATERSHED LOCATION^{a/}</u>
Citadel-Vanocker-Grizzly	SC, WC, BB
Stovho-Trebor-Rock Outcrop	SC
Paunsaugunt-Rock Outcrop	SC, WC
Barnum-Swint-St. Onge	SC, WC
Lohmiller-Glenberg-Haverson	SC, WC
Pactola-Buska-Hisega	WC, BB
Nunn-Satanta-Zigweid	WC
Kyle-Pierre-Hisle	WC
St. Onge-Keith	WC, BB
Caputa-Satanta	WC
Citadel-Vanocker	BB
Tilford-Nevee	BB
Canyon-Lakoa-Maitland	BB
a/ SC = Spearfish Creek	
WC = Whitewood Creek	
BB = Bear Butte Creek	

Source: Soil Conservation Service, 1976; 1978; 1979b.

Soil types (series) in the Black Hills are similar among the three drainages. On the plains, however, soil characteristics vary both within and between drainages. Within each drainage, the soils types depend on slope, aspect, and watershed position. Most soils in the upper reaches of the drainages are moderately deep to deep. They are well-drained and textures range from silts to loams. Soils along the foothills become deeper and more well-drained. Textures of these downstream alluvial soils range from silts and sands to clays. The nearly level bottomland and terrace soils are subject to occasional flooding. Many miles of the lower Whitewood Creek flood plain have been affected by the release of mine tailings and numerous heavy metals were identified in flood plain soils downstream of Lead and Deadwood (Fox Consultants, Inc., 1984).

The soils in the Black Hills support land uses such as woodland, wildlife habitat, rangeland, and recreation. Steep terrain in the upper drainages near the three hypothetical mine sites has prevented extensive residential development or production of crops.

Key Soil Physical and Chemical Characteristics

Selected chemical and physical characteristics of the most prevalent soils series in the three selected watersheds are provided in Table 12. Most major soils in the drainage are silty or loamy in texture. Clay content fluctuates with soil depth and type. The majority of clays occur in deeper bottomland soils or deeper in the soil profile. Upland soils are predominantly dry throughout the soil solum. Surface soil moisture fluctuates with seasons of the year. Permeability generally ranges from moderate to slow. Water retention of upland soils, which is affected by soil texture and organic matter content, is moderate. Organic matter content varies with location and depth in the profile, with surface layers of the soils containing up to 10.5 percent organic matter. Deeper in the profile, organic matter content averages less than 1 percent. The levels of calcium carbonate vary considerably with depth. Carbonates occur at depths ranging from 25 to 100 centimeters (10 to 40 inches). Overall soil pH's range from

TABLE 12

SELECTED CHEMICAL AND PHYSICAL CHARACTERISTICS
FOR THE MOST PREVALENT SOIL SERIES IN THE
WHITEMOOD, SPEARFISH, AND BEAR BUTTE CREEK WATERSHEDS

Soil Series	Texture ^{a/}	Moisture Content	To Bedrock Depth (centimeters)	Percent Clay	Percent Organic Matter	CaCO ₃ b/ (effervesces)	Nitrates b/ (meq/l)	Percent Iron	Permeability	pH
Citadel	fsl, vsl, cl	Dry throughout	150	9-43	<1-5.0	Slight	0.1	<1-2.5	Slow-moderate	5.6-8.4
Vanocker	c, sl									
Grizzly	sil, sicl, cl, l	Dry throughout	150	21-36	<1-10.5	Slight	0.1	<1-1.1	Moderate	7.3-8.4
	sil, sicl	Dry to 48 inches	150	7-44	<1-6.0	Slight	0.1	<1-3	Slow-moderate	5.6-7.3
Stovho	sil, sicl	Moist to 90 inches	150	21-45	<1-5	Mild-strong	0.1	<1-1.2	Slow-moderate	5.6-8.4
Trebor	sil, cl, l	Dry throughout	115	19-46	<1-2.8	Mild-strong	0	<1-1.8	Slow-moderate	5.6-8.4
Barnum	sl, cl	NA ^{c/}	150	NA	NA	Strong	NA	NA	Moderate	7.4-9.0
Swint	sil, l, vsl	NA	150	NA	NA	Mild-strong	NA	NA	Moderate	6.6-8.4
St. Onge	l, sil, sl, cl	NA	150	NA	NA	Mild-moderate	NA	NA	Moderate	6.6-8.4
Lohmiller	sicl	Moist throughout	150	35-55	NA	Mild	NA	NA	Slow	6.6-7.8
Glenberg	fsl, ls	Moist throughout	150	<18	NA	Slight-strong	NA	NA	Moderately rapid-rapid	6.6-8.4
Haverson	l, sil, vsl	Moist throughout	150	18-35	NA	Mild	NA	NA	Moderate	7.4-7.8
Pactola	sil, sicl	Dry throughout	150	21-29	<1-9.0	Slight	0.1	1.6-4.4	Moderate	6.1-7.3
Buska	l, sil, cl, sicl	Dry throughout	150	9-12	<1-4.0	Mild-moderate	0	2.9-3.3	Moderate	6.1-7.8
Hlaega	l	Moist throughout	180	9-14	<1-2.2	Mild	0	3.6-5.5	Moderate	6.1-7.8

a/ fsl = fine sandy loam; vsl = very fine sandy loam; cl = clay loam; c = clay; sl = sandy loam; sicl = silty clay loam; sil = silt loam; l = loam; ls = loamy sand.

b/ Measured in lowest depth of profile.

c/ Information not available

NOTE: Montmorillonite clay is moderately abundant to dominant in Citadel, Grizzly, Hlaega, Pactola, Stovho, and Trebor soils. Koalinite clay is dominant to moderately abundant in Buska, Citadel, Grizzly, Hlaega, Pactola and Stovho soils.

Source: Soil Conservation Service, 1976; 1978; 1979a; 1979b.

moderately acid (5.6) to very strongly alkaline (8.4). Most soils, however, range from slightly acid to moderately alkaline. The presence of iron is greater in soils near the towns of Lead and Deadwood along Whitewood Creek, than in the Bear Butte and Spearfish drainages. Higher iron levels in these areas may be due to historical mining activities. Soils in upper Bear Butte Creek contain moderate levels of iron.

VEGETATION

Regional Setting

A large portion of the Bear Butte Creek, Spearfish Creek, and Whitewood Creek watersheds are part of the Black Hills National Forest. Elevations within the Black Hills range from 900 meters (3,000 feet) to 2,000 meters (7,200 feet). Throughout this range in elevation there are wide variations in climate, topography, and soils, all of which affect vegetation.

Soils directly affect the kind and amount of vegetation that is present. In the Black Hills, ridge and slope soils in areas of granite and metamorphic parent material are relatively shallow, coarse textured, and well drained (Orr, 1975). These soils generally support ponderosa pine forest. The finer soil particles have been transported and deposited on lower slopes and in valley bottoms. Hence, the soils in these areas are generally finer textured, deeper, and more fertile. Lower slope and valley soils support grassland and riparian vegetation.

Vegetation throughout the region has been disturbed by fires, logging, mining, and other activities. Virtually all of the Black Hills ponderosa pine forest has been converted to a well-stocked and manageable second-growth forest (Boldt and Van Deusen, 1974). Approximately 60 percent of the Black Hills National Forest has tree stands less than 100 years old. The forest is generally composed of small diameter trees. About 75 percent of the trees are less than 9 inches diameter at breast height (d.b.h.) (U.S. Forest Service, 1983a).

Resource Use

The primary uses of the vegetation resources are livestock grazing, timber production, wildlife habitat, and recreation. Although specific data on these uses are not available for the study area, considerable resource use information is available for the Black Hills National Forest (U.S. Forest Service, 1983a) and adjacent Bureau of Land Management (BLM) land (U.S. Bureau of Land Management, 1985). The information is assumed to be representative of the general vegetation resource uses throughout the study area.

Approximately 40 percent of the Black Hills National Forest is considered suitable for livestock grazing (U.S. Forest Service, 1983a). The remainder is unsuitable because of steep topography, dense over-story vegetation, and lack of availability of water. During the 1980 grazing season, 29,600 cattle and 300 sheep, comprising 128,000 animal-unit months (AUM), were permitted to graze within the national forest. The major portion of the grazing season occurs between June 1 and October 31.

On adjacent BLM land allotments, which occur primarily at lower elevations than allotments in the Black Hills National Forest, the grazing season extends from March through December. The BLM allotments support about 74,000 AUM consisting of cattle and sheep (U.S. Bureau of Land Management, 1985).

Ponderosa pine and white spruce are the commercially important timber species. Ponderosa pine, aspen, birch, and bur oak are used for firewood (U.S. Forest Service, 1983a). The current allowable sale quantity is 34 million cubic feet (MMCF). Annual harvest levels have averaged 102 million board feet of raw timber and roundwood product material (U.S. Forest Service, 1983a). The demand for timber exceeds the current allowable sale quantity in the national forest.

Free firewood for personal use is available. With the increasing use of wood stoves and fireplaces for home heating, it is expected that the commercial firewood market will eventually develop and compete with the sawtimber and roundwood markets for available lumber (U.S. Forest Service, 1983a).

Native vegetation of some flood plains and adjacent areas has been converted to range and cropland. Crops grown include winter wheat, oats, alfalfa hay, corn, and other cereal grains (Soil Conservation Service, 1976; 1978; 1979b). Wildlife habitat and recreational uses are described in the wildlife and socioeconomic sections of this chapter, respectively.

Resource Characterization

Two major vegetation associations characterize the study area. These are ponderosa pine forest and the grassland complex of the northern Great Plains (Froiland, 1962; Severson and Thilenius, 1976). Ponderosa pine forest is the predominant vegetation type in the Black Hills, and covers more than 90 percent of the Black Hills area. At lower elevations, where the forest and plains meet, the forest in some places develops into an open ponderosa pine savannah (Froiland, 1962). Elsewhere, there is an abrupt transition from forest to grassland.

Grasslands dominate the lower elevations and more level or less mountainous portions of the study area. The primary plains grassland type consists of wheatgrass and needlegrass. Grasslands are also interspersed with forest vegetation in the Black Hills. Drier, shallow soils support mixed prairie grasslands while moist, deep soils support bluegrass grasslands.

At lower elevations, riparian vegetation typically consists of cottonwood stands or stands of bur oak, American elm, green ash, and eastern hop hornbeam (Froiland, 1962). At higher elevations, white spruce, aspen, and paper birch form locally dense stands along streams and on north-facing slopes (Pase, 1958). Willow, water birch, and other shrubs become more abundant in riparian communities at the highest elevations.

Ponderosa pine, grasslands, aspen, and white spruce are the dominant vegetation types in the Black Hills National Forest (Table 13).

TABLE 13
PERCENTAGE OF VEGETATION TYPES OCCURRING IN THE
BLACK HILLS NATIONAL FOREST

<u>Vegetation Type</u>	<u>Percent of Forest Total</u>
Aspen	2.0
Grassland	6.6
Ponderosa pine	88.0
Wetlands	0.7
White spruce	1.0
Other	1.7

Source: U.S. Forest Service, 1983a.

Aspen

Aspen is a relatively minor vegetation type in the study area. In the Black Hills National Forest this type comprises about 2 percent of the total vegetation cover (U.S. Forest Service, 1983a). The dominant species in the aspen forest are aspen, Woods rose, common snowberry, spirea, and various forbs and grasses (U.S. Forest Service, 1986a).

Aspen stands primarily occur on relatively steep slopes with northern or eastern exposures (Severson and Thilenius, 1976). The elevational range for aspen in the Black Hills is 1200 to 2100 meters (4000 to 7000 feet).

The Black Hills aspen stands described by Severson and Thilenius (1976) ranged from dense stands of small, young trees to open, park-like stands of large trees. The majority of stands had trees which were only 20 to 40 years old. The trees were usually less than 10 centimeters (4 inches) d.b.h., although several stands had trees in the 10- to 20-centimeter (4- to 8-inch) d.b.h. size class. Few stands contained larger trees. Many of the aspen stands had apparently developed following wildfires in the 1930's.

Because of the generally lush understories of aspen stands and their frequent proximity to water, aspen stands are important to livestock and to a wide variety of wildlife. Cattle, elk, and mule deer use aspen stands for forage, escape and thermal cover, and for calving (Hoover and Wills, 1984). In the Black Hills, aspen is also used for firewood.

Grasslands

Grasslands in the study area can be subdivided into two major categories for purposes of discussion: plains grasslands and mountain grasslands. The salient characteristics of these grasslands are described below.

Plains grasslands are typified by the wheatgrass grassland and the wheatgrass/blue grama grassland (Johnson and Nichols, 1970; U.S. Bureau of Land Management, 1985). These mid-grass grasslands are both dominated by western wheatgrass. A variety of other grass and forb species occur to form a series of complex prairie associations. These grasslands occupy the gently rolling prairies throughout western South Dakota and in the northern portions of the study area.

Plains grasslands are generally highly productive, although production can vary with temperature, precipitation, and grazing pressure. Most of the historical prairie in the region has been grazed by domestic livestock for a long time (Soil Conservation Service, 1978). Significant acreages of plains grasslands have been converted to cropland.

The two main types of mountain grasslands in the Black Hills are the mixed prairie grassland and the bluegrass grassland (Severson and Thilenius, 1976). The mixed prairie grassland consists of needle and thread grass, blue grama, little bluestem, big bluestem, and western wheatgrass and occurs on shallow, well-drained soils on south- and west-facing slopes (Thilenius, 1971; Severson and Thilenius, 1976). These primary grasses can occur in various combinations and relative abundances, giving rise to several different community types.

The bluegrass grassland, dominated almost exclusively by Kentucky bluegrass, generally occurs along streams or, at higher elevations, on deep, moist soils derived from sedimentary and metamorphic materials (Severson and Thilenius, 1976). Mountain grasslands provide an important source of forage for livestock and wildlife species.

Ponderosa Pine

The general appearance of the Black Hills is a uniform forest of ponderosa pine. However, there is a great deal of variation in the forest understory. Six to ten ponderosa pine subtypes occur in the study area (Thilenius, 1971; U.S. Forest Service, 1986a).

Ponderosa pine can be found on all slope aspects and throughout the elevational range of the Black Hills. Stands vary from densely stocked to open savannah in appearance. The more open stands have higher forage production than the dense stands (Pase, 1958) and therefore are of greater forage value to livestock and wildlife. Intermediate and densely stocked stands of ponderosa pine offer good wildlife cover but little forage.

Ponderosa pine makes up 95 percent of the commercial timber volume in the Black Hills (Pase, 1958). White spruce accounts for the remaining 5 percent.

Wetlands

Wetlands occupy about 1 percent of the land in the national forest. The following wetland communities may exist in the study area: plains riparian woodlands, mountain riparian woodlands, riparian shrublands, and sedge meadows. Other wetland types include various water bodies in the area.

Plains riparian woodlands consist of stands containing various combinations and relative abundances of plains cottonwood, eastern cottonwood, narrow-leaf cottonwood, American elm, willow, box elder, Russian olive, and bur oak (Severson and Thilenius, 1976; Fox Consultants, Inc., 1984; U.S. Bureau of Land Management, 1985). Plains riparian woodlands occupy narrow corridors along major streams and

rivers in the lower elevations of the study area. These stands vary in density and other basic vegetation characteristics in response to changes in elevation, stream gradient, and local hydrology.

Progressing upstream into the Black Hills, the mountain riparian woodlands exhibit changes in composition. The cottonwoods generally are not as prevalent in the mountains as they are on the plains. The dominant tree species are aspen and paper birch (Froiland, 1962; Severson and Thilenius, 1976). American elm, green ash, box elder, and hop hornbeam may also be locally common. Willows, red-osier dogwood, and river birch form the understory in the mountain riparian woodlands. Willows may assume local dominance in some areas and can form riparian shrubland communities at higher elevations (Froiland, 1962; Thilenius, 1971).

Sedge meadows are limited in extent in the study area. They occur in the Black Hills in low areas adjacent to streams and behind silted-in beaver dams (Thilenius, 1971). Depending on hydrologic regime, these meadows may be dominated by Nebraska sedge, other species of sedges, tufted hairgrass, or reedgrass.

All of these riparian communities are very valuable to wildlife and livestock and are used to a disproportionately greater extent than other habitat types (Hirsh and Segelquist, 1978; Sands, 1978; Hoover and Wills, 1984). The linear configuration of riparian systems, their proximity to aquatic systems, and the physical and chemical interactions between the riparian and aquatic systems provide a great number and variety of habitats that are occupied by numerous organisms at all trophic levels. The majority of rare plant species listed for the Black Hills occur in riparian habitats.

White Spruce

White spruce stands, although they occupy only 1 percent of the Black Hills National Forest, are commercially important for lumber. About 5 percent of the commercially harvested timber in the Black Hills is white spruce.

White spruce occurs in moist habitats and reaches its best development on north-facing slopes or along streams at higher elevations in the Black Hills (Thilenius, 1971; U.S. Forest Service, 1986a). The understory is generally sparse.

Cropland

Crops are grown on the plains in the northern portion of the study area. The majority of crops are grown in flood plains of the major water courses and on upland plains of the area. The main crops are winter wheat, oats, and alfalfa hay. Corn, sorghum, spring wheat, barley, and rye are also grown (Soil Conservation Service, 1976; 1978; 1979b).

Other Vegetation and Land Use Types

Other minor types of vegetation and land use occur in the study area. These include various shrubland types, disturbed land, water bodies, and residential areas. None is extensive in areal coverage and their use as vegetation resources for livestock and wildlife is limited.

Special Concern Plant Species

The flora of the Black Hills contains a diverse assemblage of plant species representative of the Rocky Mountain region, the northern boreal forest, the eastern Great Plains, and the eastern deciduous forest (Severson and Thilenius, 1976). As a consequence, many species are at the edge of their distributional ranges and are considered rare in the Black Hills even though they may be common elsewhere.

The South Dakota Department of Game, Fish, and Parks (1986) prepared a list of special concern plant species for the Bear Butte Creek, Spearfish Creek, and Whitewood Creek watersheds. No candidate or federally-listed threatened or endangered plant species are known to occur in these watersheds. Plants occurring along streams and floodplains in these watersheds, and which are considered rare or uncommon, are listed in Table 14.

TABLE 14
SPECIAL CONCERN PLANT SPECIES IN BEAR BUTTE CREEK,
SPEARFISH CREEK, AND WHITEWOOD CREEK WATERSHEDS

<u>Plant Species and Drainage</u>		<u>Division of Wildlife Natural Heritage Inventory Status</u>
<u>Bear Butte Creek</u>		
Alder buckhorn	<u>Rhamnus alnifolia</u>	Undetermined
<u>Spearfish Creek</u>		
Alaska oniongrass	<u>Melica subulata</u>	Rare
Alpine rush	<u>Juncus alpinus</u>	Rare
Beautiful fleabane	<u>Erigeron formosissimus</u>	Undetermined
Dwarf scouring rush	<u>Equisetum scirpoides</u>	Rare (disjunct)
Fairy slipper orchid	<u>Calypso bulbosa</u>	Rare
Green spleenwort	<u>Asplenium viride</u>	Rare (disjunct)
Hair sedge	<u>Carex capillaris</u>	Rare (peripheral)
Hood's sedge	<u>Carex hoodii</u>	Undetermined
Jointed rush	<u>Juncus arcticulatus</u>	Rare
Kidney leaf violet	<u>Viola renifolia</u>	Undetermined
Low northern sedge	<u>Carex concinna</u>	Rare (disjunct)
Maidenhair fern	<u>Adiantum pedatum</u>	Historical record
Moonwort	<u>Botrychium lunaria</u>	Historical record
Musk-root	<u>Adoxa moschatellina</u>	Rare (disjunct)
Northern white-orchid	<u>Platanthera dilatata</u>	Rare
One-flower wintergreen	<u>Pyrola uniflora</u>	Undetermined
Rattlepod	<u>Astragalus americanus</u>	Rare (disjunct)
Ground pine	<u>Lycopodium obscurum</u>	Undetermined
Round-leaved orchid	<u>Platanthera orbiculata</u>	Historical record
Small white violet	<u>Viola macloskeyi</u>	Undetermined
Squashberry	<u>Viburnum edule</u>	Rare
Tufted hairgrass	<u>Deschampsia cespitosa</u>	Rare (peripheral)
Western mountain ash	<u>Sorbus scopulina</u>	Rare
Western saxifrage	<u>Saxifraga occidentalis</u>	Rare (disjunct)
White-vein wintergreen	<u>Pyrola picta</u>	Rare (disjunct)
<u>Whitewood Creek</u>		
Broad-lipped twayblade	<u>Listera convallarioides</u>	Critically rare
Delicate sedge	<u>Carex leptalea</u>	Rare
Green spleenwort	<u>Asplenium viride</u>	Rare (disjunct)
Hair sedge	<u>Carex capillaris</u>	Rare (peripheral)
Hood's sedge	<u>Carex hoodii</u>	Undetermined
Northern white orchid	<u>Platanthera dilatata</u>	Rare
Rattlepod	<u>Astragalus americanus</u>	Rare (disjunct)
Small white violet	<u>Viola macloskeyi</u>	Undetermined
Small-flowered woodrush	<u>Luzula pariflora</u>	Undetermined
Western mountain ash	<u>Sorbus scopulina</u>	Rare
Western saxifrage	<u>Saxifraga occidentalis</u>	Rare (disjunct)
White-vein wintergreen	<u>Pyrola picta</u>	Rare (disjunct)

Source: South Dakota Department of Game, Fish, and Parks, 1986.

WILDLIFE

General Wildlife Resources

There are no wildlife refuges or other areas within the study area managed specifically for wildlife by federal agencies. However, the South Dakota Department of Game, Fish, and Parks has several properties in each watershed that provide some relatively undeveloped land for wildlife. Wildlife resources in the study area are readily accessible to the public because of the abundance of public lands, both federal and state.

Regional wildlife resources are diverse in type, with all major wildlife groups represented (Table 15). The wildlife composition is strongly influenced by the topographic conditions and vegetation types present. Because most of the study area consists of upland vegetation and habitat types, the overall wildlife character of the area is upland. Semi-aquatic wildlife species such as waterfowl, shorebirds, beaver, and muskrat are relatively uncommon, but may be abundant where suitable habitat occurs.

The Black Hills and plains environments support different assemblages of wildlife species. For example, principal wildlife species associated with the ponderosa pine areas of the Black Hills include elk, deer, porcupine, gray fox, red squirrel, sharp-shinned hawk, Cooper's hawk, dipper, nuthatches, American robin, turkey, and ruffed grouse (U.S. Forest Service, 1986a). Principal species associated with the grassland vegetation types of the plains environment include deer, coyote, red fox, black-tailed prairie dog, badger, pronghorn, golden eagle, sharp-tailed grouse, turkey vulture, red-tailed hawk, western meadowlark, and grasshopper sparrow (U.S. Forest Service, 1986a).

To simplify discussion of the large number of species, description of the wildlife resource is accomplished by wildlife group (see Table 15). Species of special concern (primarily threatened or endangered species) are discussed as a separate group. The comprehensiveness and

TABLE 15
SUMMARY OF GENERAL WILDLIFE RESOURCES CHARACTERISTICS

Wildlife Group	Number of Species	Common Representatives	Common Vegetation Associations	Comments
Large mammals	6	• Elk • Deer • Pronghorn	• Ponderosa pine • Aspen • Grassland	• Most representatives of this group are popular game species.
Small mammals	57	• Deer mouse • Least chipmunk • Fox squirrel • Meadow vole	• Ponderosa pine • Aspen • White spruce • Grassland	• Species composition diverse and all vegetation types occupied.
Furbearers	17	• Beaver • Muskrat • Coyote	• Ponderosa pine. • Aspen • Grassland	• Except for muskrat and beaver, members of this group tend to possess large home ranges.
Waterbirds	57	• Mallard • Green-winged teal	• Wetlands	• Most representatives of this group are migrants.
Upland birds	9	• Turkey • Mourning dove	• Ponderosa pine • Aspen • Grasslands	• Species mixture changes seasonally.
Raptors	26	• Golden eagle • American kestrel • Red-tailed hawk • Great horned owl	• Ponderosa pine • Grasslands	• Members of this group tend to hunt large territories.
Songbirds	147	• American robin • Red-winged blackbird • Dark-eyed junco • Western meadowlark	• Ponderosa pine • Grasslands • Wetlands	• Species composition is diverse, all vegetation types are occupied, and species mixture changes seasonally.
Amphibians and Reptiles	26	• Tiger salamander • Leopard frog	• Ponderosa pine • Wetlands	• All vegetation types are occupied.

Sources: American Ornithologists' Union, 1983; U.S. Forest Service, 1983b; MacCracken, 1984; Sharps and Benzon, 1984; U.S. Bureau of Land Management, 1985; Vandell, 1986.

specificity of available data for species and groups of species are quite variable. Generally, information on game species is the most extensively developed.

Large Mammals

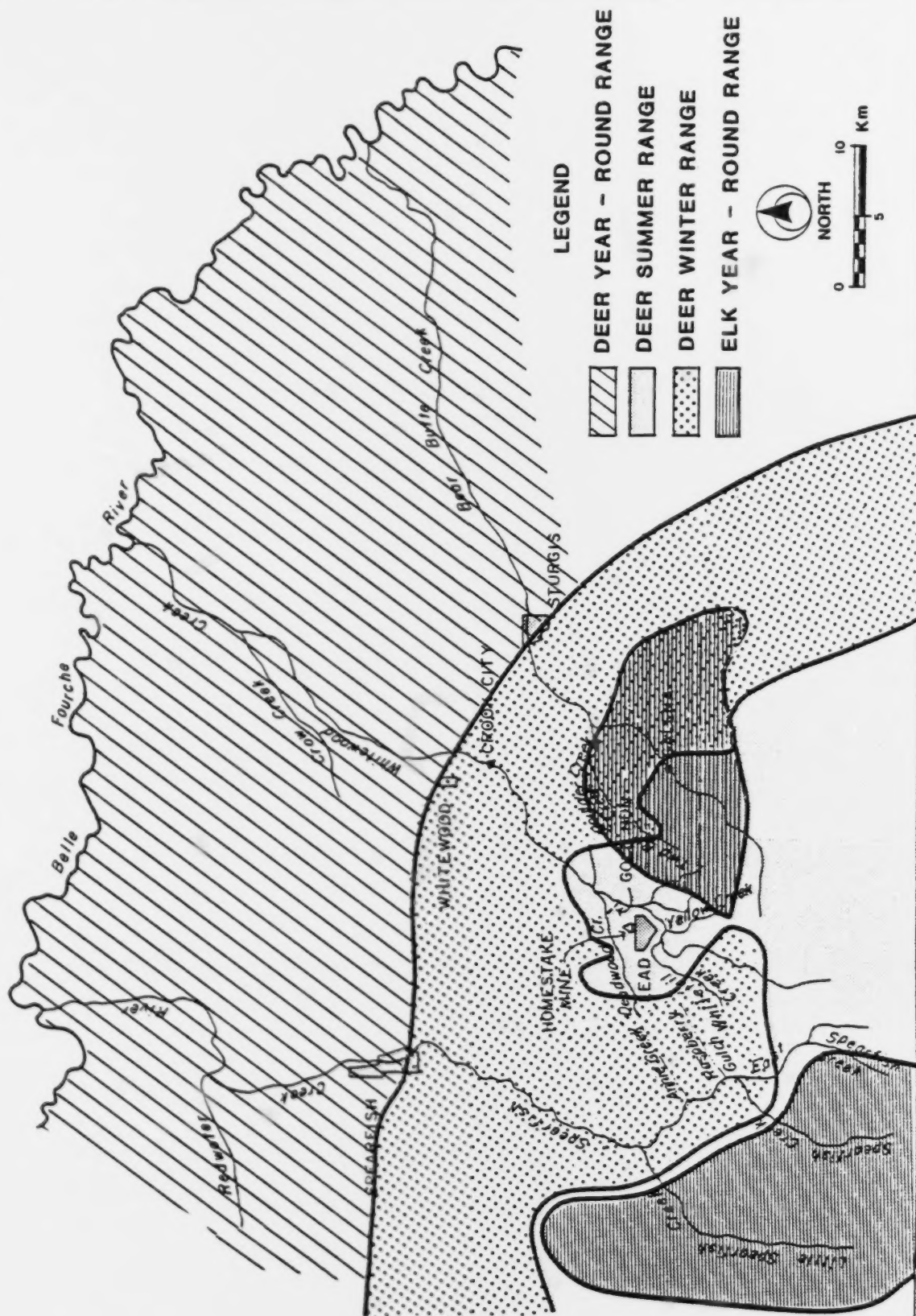
Six species of large mammals potentially occur within the study area: elk, mule deer, white-tailed deer, pronghorn antelope, black bear, and mountain lion. Mule deer and white-tailed deer are the most widely distributed species. Elk and antelope are more restricted; they are found only in two portions of the study area and on the plains, respectively. Black bear and mountain lion are classified as threatened species by the State and are included in the discussion of species of special concern.

White-tailed deer and mule deer are the most abundant and widespread large mammals in the study area, and occur in all three watersheds. However, mule deer are most common in the Spearfish Canyon area (Haeder, 1981). White-tailed deer appear to outnumber mule deer by about three or four to one and are the most popular game species (Haeder, 1981; U.S. Forest Service, 1983a). Approximately 50,000 white-tailed deer, and 10,500 mule deer inhabit the Black Hills National Forest (U.S. Forest Service, 1983a). Approximately 10,000 mule deer and white-tailed deer inhabit the Black Hills portion of the study area (B. Parrish, South Dakota Department of Game, Fish, and Parks, personal communication, 1986). Their long-term population trend has been downward.

Deer winter range, summer range, and year-round range occur in the study area (Figure 12). The hypothetical heap leach operations in the Spearfish and Bear Creek drainages are both located in winter range. The Whitewood Creek site is in summer range. Both winter and summer ranges are considered critical habitat.

Swales, draws, lowlands, and river and creek flood plains make up the most important white-tailed deer habitat (Petersen, 1984). The deer use gently rolling upland areas the least. In western South Dakota, white-tailed deer are primarily associated with coniferous

FIGURE 12
ELK AND DEER HABITAT FEATURES



(SOUTH DAKOTA DEPARTMENT OF GAME, FISH, AND PARKS)

forest and riparian areas (U.S. Bureau of Land Management, 1985). The ponderosa pine vegetation type is used extensively.

Mule deer can be found in most, if not all, of the vegetation types occurring in the study area. However, they tend to prefer grassland/shrubland, coniferous forest, and riparian areas (Severson, 1981; U.S. Bureau of Land Management, 1985). Mule deer will use the somewhat drier, shrubby areas (such as juniper draws found in rough breaks in the terrain) more heavily than will white-tailed deer (Petersen, 1984). During the fall and winter, mule deer prefer more open habitats over the heavily wooded slopes frequented during the summer (Severson, 1981).

Elk and pronghorn antelope are relatively limited in their occurrence within the study area. Pronghorn occupy the plains environment in the northern part of the study area. Approximately 400 elk inhabit the Black Hills portion of the study area. Thirty to 50 elk inhabit the eastern area of range and about 350 head occur in the western area. Two areas have been identified as elk year-round range (Figure 12). The hypothetical heap leach operations on Whitewood and Bear Butte Creeks are located on the west and north edges, respectively, of the eastern area of elk range. The Spearfish Creek site does not occur in mapped elk range (Figure 12).

Furbearers

Approximately 17 species of furbearers potentially occur in the study area (Sharps and Benzon, 1984; U.S. Forest Service, no date; U.S. Forest Service, 1983b). Species known to occur in the area include the coyote, raccoon, red fox, gray fox, long-tailed weasel, striped-skunk, beaver, and muskrat. Generally, furbearers are secretive and easily overlooked.

Furbearer species composition and number of individuals vary by vegetation type. Species most likely to occur in the widespread ponderosa pine forest include the coyote, red fox, long-tailed weasel,

and striped skunk. Beaver, muskrat, and mink are essentially restricted to wetland and riparian vegetation types. Common species of the more open grassland vegetation type include the coyote, badger, and long-tailed weasel.

Small Mammals

Approximately 57 species of small mammals potentially occur in the study area (U.S. Forest Service, 1983b; Sharps and Benzon, 1984). Small mammal species composition and number of individuals within any geographical area vary with vegetation type and season. Common species of the Black Hills environment include the deer mouse, red squirrel, least chipmunk, Nuttall's cottontail, and porcupine. The black-tailed jackrabbit, thirteen-lined ground squirrel, deer mouse, and meadow vole are typical species of the plains environment.

Waterbirds

Approximately 57 species of waterbirds potentially occur in the study area (American Ornithologists' Union, 1983; U.S. Forest Service, 1983b; Sharps and Benzon, 1984). Included are 21 species of waterfowl and 26 species of shorebirds. Species composition and number of individuals within any given geographical area vary with vegetation type and characteristics of the local water bodies.

Waterfowl habitat occurring within the study area is of relatively low quality. Desirable areas such as extensive ponds, marshes, and larger oxbow pools are not present. Some waterfowl production probably occurs in the general area but it is relatively minor in comparison with the remainder of South Dakota (Brewster et al., 1976).

Waterfowl species composition varies with the season. Few species and lower numbers of individuals are expected to occur during the summer because the area provides very limited breeding habitat and that which is present is attractive to only a small number of species. Use by waterbirds peaks during the spring and fall migration periods.

Upland Birds

Nine species of upland birds potentially occur within the study area (U.S. Forest Service, 1983b; Sharps and Benzon, 1984). Species composition and number of individuals within any given geographical area vary with vegetation type and season. Upland birds occurring in the Black Hills environment include the turkey, ruffed grouse, sharp-tailed grouse, and mourning dove. The sharp-tailed grouse, ring-necked pheasant, and mourning dove occur in the plains environment.

The wild turkey is probably the most widespread upland bird species in the study area (U.S. Bureau of Land Management, 1985; Parrish, 1986; U.S. Forest Service, no date). It is also the second most popular game species in the Black Hills after white-tailed deer (Haeder, 1981). Approximately 5,000 turkeys inhabit the Black Hills portion of the study area (B. Parrish, South Dakota Department of Game, Fish, and Parks, personal communication, 1986). Although, the turkey population presently appears to be stable the objective is to increase the population to about 10,000 birds (U.S. Forest Service, 1983a).

Raptors

Approximately 26 species of raptors potentially occur within the study area (American Ornithologists' Union, 1983; U.S. Forest Service, 1983b; Sharps and Benzon, 1984). Included are 16 species of diurnal birds of prey and 9 species of owls. Common species include the sharp-shinned hawk, northern harrier, red-tailed hawk, golden eagle, American kestrel, and great horned owl. Raptor species composition and number of individuals within any given geographical area vary with vegetation type and season.

Although the majority of raptor species potentially occurring in the study area are generally tolerant of a wide variety of vegetation types, preferences for certain features are common. Old-growth forests are important to many of the owls because they are the major source of

snags which the cavity-nesting species require (Rapheal and White, 1984). Cliffs occurring in the study area are potentially important as nest sites, particularly for golden eagles, red-tailed hawks, and prairie falcons.

Nests of breeding raptors undoubtedly occur in all three watersheds. Most probably have not been documented because many species are inconspicuous and difficult to observe during the nesting season. Nesting sites include snags, cliffs, tree tops, and the ground. The more prominent breeding species include the golden eagle, red-tailed hawk, and turkey vulture.

Songbirds

Approximately 147 species of songbirds potentially occur within the study area (American Ornithologists' Union, 1983; U.S. Forest Service, 1983b; Sharps and Benzon, 1984). Species composition and number of individuals within any given geographical area vary with vegetation type and season. Most of the vegetation types have relatively large numbers of potentially occurring species.

Snags, which provide numerous nest-cavities, are found mainly in old-growth forests and are particularly important to many species of songbirds (Raphael and White, 1984). Riparian and wetland habitats are also considered important in the study area because of their limited availability and attractiveness to a relatively large number of songbird species.

Songbird species composition varies with the season. Approximately 38 species (26 percent of the total songbird species in the study area) are considered to be year-round residents and 89 (60 percent) are present only during the summer (American Ornithologists' Union, 1983). The remaining 20 species (14 percent) are present only during the spring and fall migration periods or the winter months.

Amphibians and Reptiles

Approximately 26 species of amphibians and reptiles potentially occur within the study area (U.S. Forest Service, 1983b; Sharps and Benzon, 1984). Included are 7 species of amphibians and 19 species of reptiles.

Species of amphibians and reptiles potentially inhabit all of the vegetation types present. However, riparian and wetland vegetation types are especially important to amphibians, which require surface water to complete portions of their life cycles. Most reptiles prefer drier shrublands and open coniferous forest. Amphibians may also be found in these drier habitats during the nonbreeding season.

Species of Special Concern

Several wildlife species of special concern potentially occur in the study area (Table 16). Species of special concern include federal- and state-listed threatened or endangered species and species that are proposed or are candidates for listing as threatened or endangered species. Some state-listed species, such as the black bear, are of concern due to limited numbers in South Dakota, even though they may be common in other states.

Specific information about species occurrence in the three watersheds is relatively limited. The peregrine falcon, osprey, and bald eagle are migrants. However, efforts are presently being made to reintroduce peregrine falcon breeding pairs in the Black Hills (U.S. Forest Service, 1983a). The presence of black-footed ferrets would be limited to black-tailed prairie dog colonies that may occur in the lower plains reaches of each watershed. Little is known about the occurrence of the other species in the study area since documented observations are lacking (Vandel, 1986).

Most of the special concern species primarily occur in upland vegetation types such as ponderosa pine. The bald eagle and osprey are also strongly associated with aquatic and riparian communities. Peregrine falcons also tend to be associated with riparian vegetation.

TABLE 16

SPECIAL CONCERN WILDLIFE SPECIES POTENTIALLY
OCCURRING IN THE STUDY AREA

<u>Species</u>	<u>Official Designation</u> ^{a/}	<u>Comments</u>
Ferruginous hawk	CL	Restricted to grasslands
Swainson's hawk	CL	Common summer resident of grasslands bit population is declining
Mountain plover	CL	Last breeding records were from Black Hills area in 1929
Peregrine falcon	FE, SE	Rare migrant; breeding pairs are being intro- duced to the Black Hills
Bald eagle	FE, SE	May nest in South Dakota
Long-billed curlew	CL	Uses short-grass plains
Osprey	ST	Rare migrant
Mountain lion	ST	Spotty distribution in Black Hills
Lynx	CL	Extremely low numbers
Black-footed ferret	FE, SE	Associated with prairie dog colonies
Black bear	ST	Habitat decreasing
Swift fox	CL, ST	Habitat decreasing

a/
 FE: Federally Endangered
 FT: Federally Threatened
 CL: Candidate for Federal Listing
 SE: State Endangered
 ST: State Threatened

Source: Houtcooper et al., 1985; U.S. Forest Service, 1983b; Sharps
and Benzon, 1984.

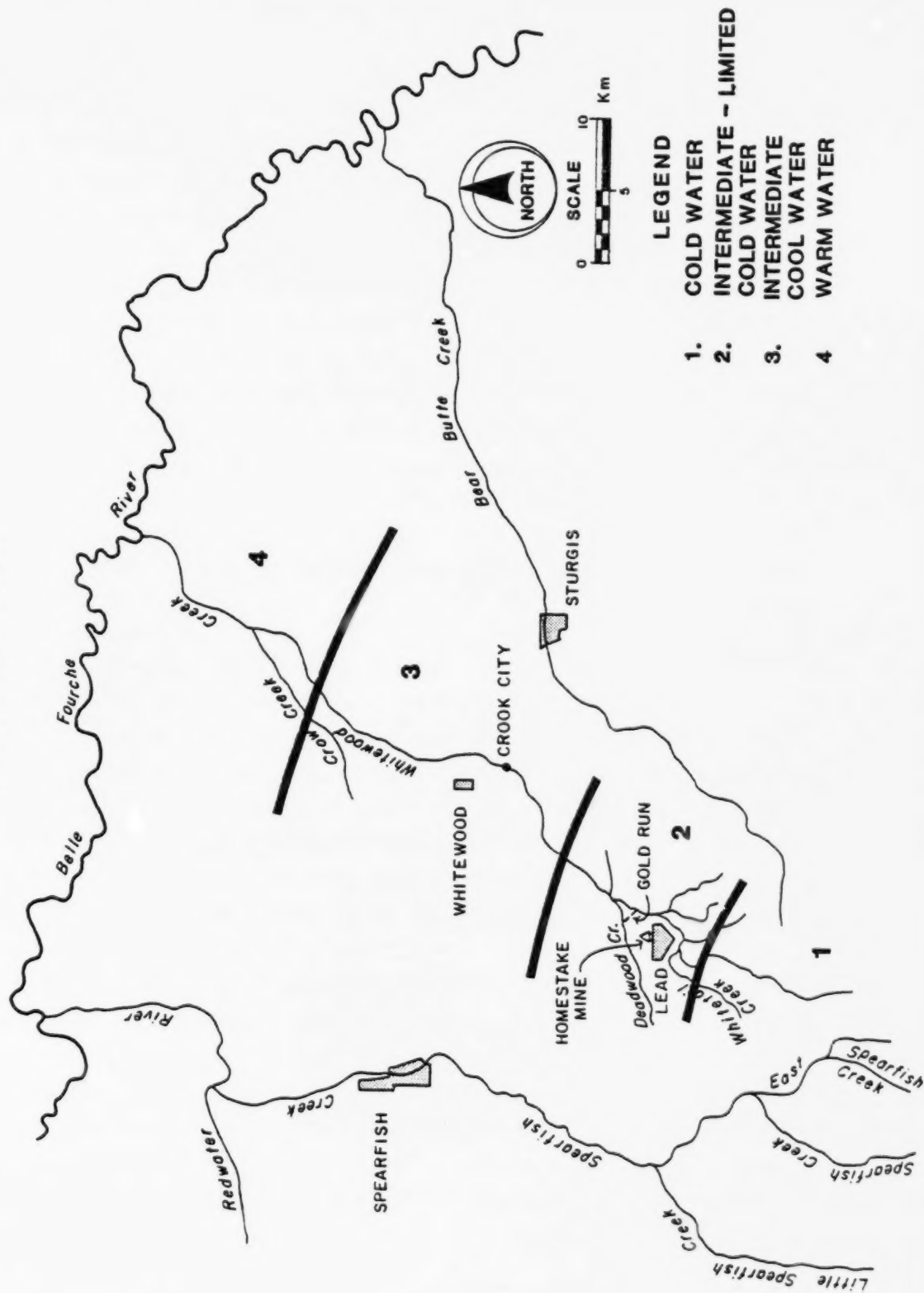
AQUATIC LIFE

Aquatic life information for Bear Butte, and Spearfish Creeks is limited. However, because of mining activities near Whitewood Creek, information on that creek is available from several sources. Herricks (1982) sampled Whitewood Creek from its headwaters to the confluence with Belle Fourche River for water quality, stream morphometry, riparian vegetation, aquatic macroinvertebrates, periphyton, and fish. He also sampled Spearfish Creek for fish at one station, and for aquatic macroinvertebrates at three stations. Fox Consultants, Inc. (1984) sampled the downstream reaches of Whitewood and Spearfish Creeks for fish and aquatic macroinvertebrates. The South Dakota Division of Wildlife has sampled Spearfish and Bear Butte Creeks for fish in 1984 and 1985. Concurrently, macroinvertebrate sampling was conducted on these creeks by South Dakota State University, but the information is not yet available.

Whitewood Creek

Herricks (1982) defined four aquatic life zones of Whitewood Creek (Figure 13). The cold water zone occurs from the headwaters to immediately upstream from Whitetail Creek. This zone is characterized by cold water, depths less than 0.15 meter (0.5 feet), a steep gradient of 4 percent, and an aquatic community dominated by cold water species. A transition zone, called intermediate limited cold water, exists from the end of the cold-water zone to about Crook City. This stretch contains well-developed pools and riffles, has a moderate gradient, and includes both cold-water and warm-water species. A second intermediate zone called intermediate - cool water, was defined from Crook City to Township 7 North, Range 4 East, Section 25 of Lawrence County. This stretch has a lower gradient than the upper intermediate zone. The warm-water zone was characterized as having extended pool and depositional habitat, short riffles, shallow depths, a low gradient, and warm-water flora and fauna. The South Dakota Board of Water Management has classified the segment of Whitewood Creek upstream from Interstate

FIGURE 13
AQUATIC LIFE ZONES IN
WHITEWOOD CREEK



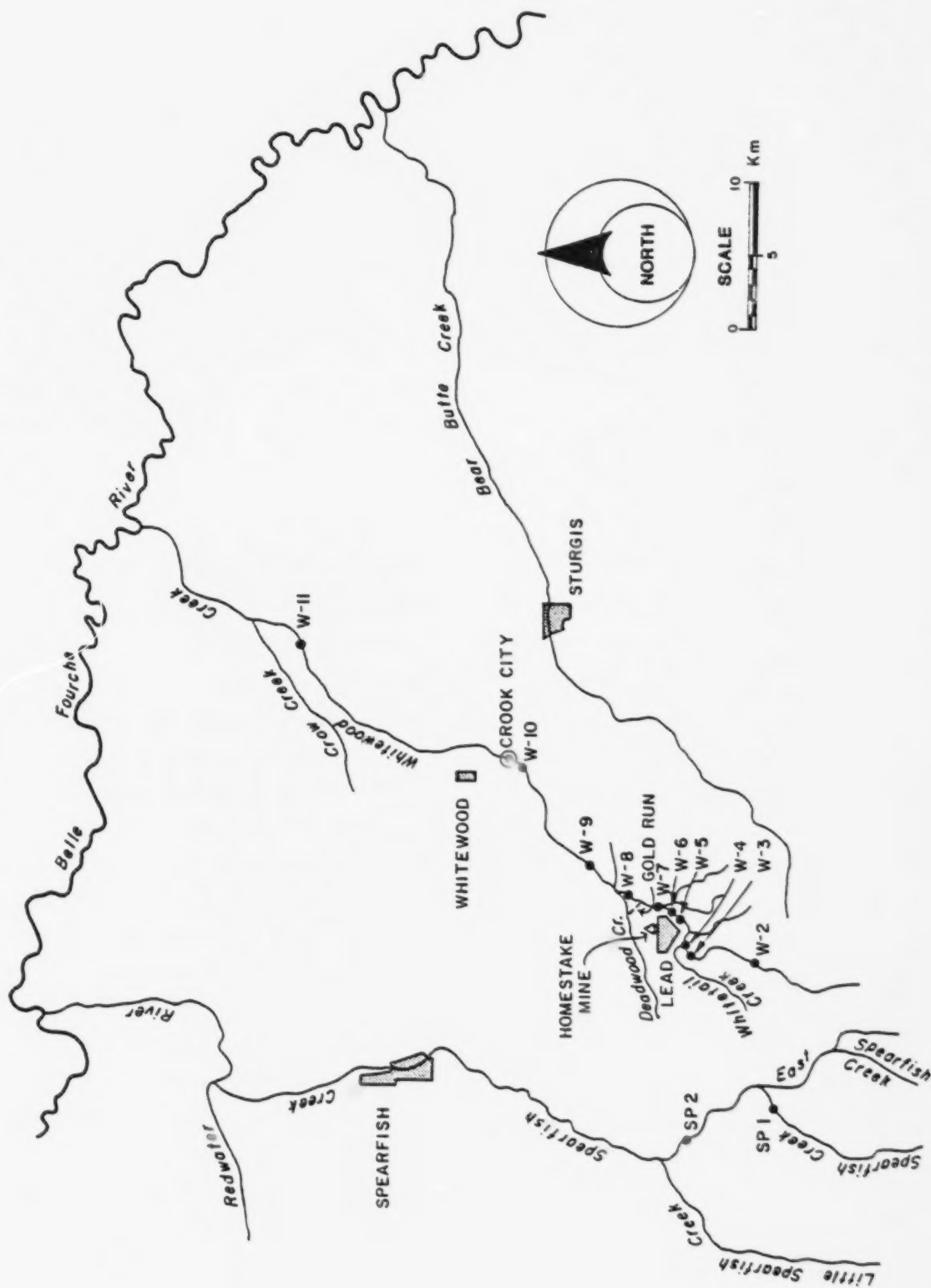
(MODIFIED FROM HERRICKS, 1982)

90 to Gold Run Creek as "cold water marginal fishlife propagation" which protects for stockings of catchable-size trout but does not protect for fish reproduction.

Physical measurements were made throughout Whitewood Creek by Herricks (1982). The location of morphometry sampling points are shown on Figure 14. As would be expected, width and discharge increased from upstream to downstream while gradient and percent of shaded area decreased (Table 17). Mean depth increased slightly from 0.12 meter (0.4 feet) to 0.18 meter (0.6 feet). Generally, particle size of substrate decreased from upstream to downstream, but larger particles (rubble and gravel) remain predominant below station W3 (Table 18). Silt covers nearly 50 percent of the stream bottom at station W9 and may be related to the influence of discharge from the Lead-Deadwood Wastewater Treatment Plant. Streambank conditions are generally stable although severe erosion was noted at station W6 and minor disturbances occur throughout the stream length (Table 17). Trees and brush are predominant in the riparian areas upstream from Lead, and grass and bare soil cover the banks downstream from Lead.

Whitewood Creek receives discharges from the coal-fired Kirk Power Plant immediately upstream from the town of Lead; from Gold Run, a tributary which carries the effluent from the Homestake Mining Company; and from the Lead-Deadwood and Whitewood wastewater treatment plants. The Lead-Deadwood wastewater treatment plant is a secondary-partial tertiary facility which was installed in 1979. The temperature of the effluent is 15 to 20 °C (60 to 70 °F) and the ammonia concentrations are typically 0.1 to 0.5 mg/l. The Whitewood facility provides secondary treatment and is not as sophisticated as the Lead-Deadwood facility (Lead-Deadwood Wastewater District, 1986). The Kirk Power Plant is equipped with two cooling towers which cool the effluent to 15 to 20 °C (60 to 70 °F) (T. Stalcup, Kirk Power Plant, personal communication, 1986). The Homestake effluent is warmed by water from the mine, but the temperature of Whitewood Creek downstream from the confluence with Gold Run is regulated to remain below 24 °C (75 °F). Bacterial degradation treatment of the effluent began in 1984 and has

FIGURE 14
LOCATIONS OF PHYSICAL MEASUREMENTS



MODIFIED FROM HERRICKS, 1982)

TABLE 17
SUMMARY OF PHYSICAL MEASUREMENTS OF WHITEWOOD AND SPEARFISH CREEKS

Station	Mean Width (meters)	Mean Depth (meters)	Mean Velocity (m/s)	Mean Discharge (m ³ /s)	Riffle: Pool	Stream Gradient (percent)	Shaded Stream Area (percent)	Bank Stress
Whitewood Creek								
W2	2.1	0.12	0.27	0.11	1:2	4.5	45	road, RR
W3	1.7	0.06	0.21	0.03	1:1	2.5	45	erosion, ash pile
W4	4.75	0.12	0.30	0.14	1:1	3.0	20	road, erosion
W5	4.57	0.12	0.27	0.16	1:1	2.0	30	road, construction
W6	4.60	0.15	0.15	0.15	1:1	2.9	30	construction, erosion, road
W7	4.85	0.12	0.70	0.32	3:1	2.3	10	road, channelized, RR
W8	5.94	0.18	0.37	0.34	2:1	1.8	10	road, channelized
W9	7.38	0.21	0.30	0.45	2:1	1.1	20	road, mine
W10	6.61	0.18	0.46	0.42	2:1	1.9	35	grazing
W11	9.97	0.15	0.46	0.48	4:1	0.8	10	grazing
Spearfish Creek								
SP1	4.63	0.27	0.27	0.27	1:4	2.0	50	road, summer homes
SP2	7.47	0.37	0.24	0.56	3:1	2.3	60	recreation

Source: Modified from Herricks, 1982.

TABLE 18
SUMMARY OF SUBSTRATE MEASUREMENTS OF WHITEWOOD AND SPEARFISH CREEKS

Station	Percent of the Bottom Covered by					Plants	Debris	Embeddedness (percent)
	Boulder	Rubble	Gravel	Sand	Silt			
Whitewood Creek								
W2	40	15	0	0	25	20	0	45
W3	55	30	10	5	0	0	0	30
W4	9	24	20	27	10	10	0	35
W5	3	28	21	14	22	12	0	20
W6	14	29	19	7	24	0	7	25
W7	6	71	10	5	7	0	1	20
W8	20	35	25	10	5	0	5	45
W9	0	17	38	3	42	0	0	60
W10	14	21	51	5	8	0	1	35
W11	0	35	47	5	10	2	1	60
Spearfish Creek								
SP1	2	12	17	21	3	43	2	60
SP2	10	45	20	15	0	5	5	70

Source: Modified from Herricks, 1982.

rendered the effluent non-toxic (F.D. Fox, Homestake Mining Company, personal communication, 1986). Before 1984, the effluent contained concentrations of cadmium, copper, cyanide, iron, lead, nickel, silver, and zinc which adversely impacted Whitewood Creek.

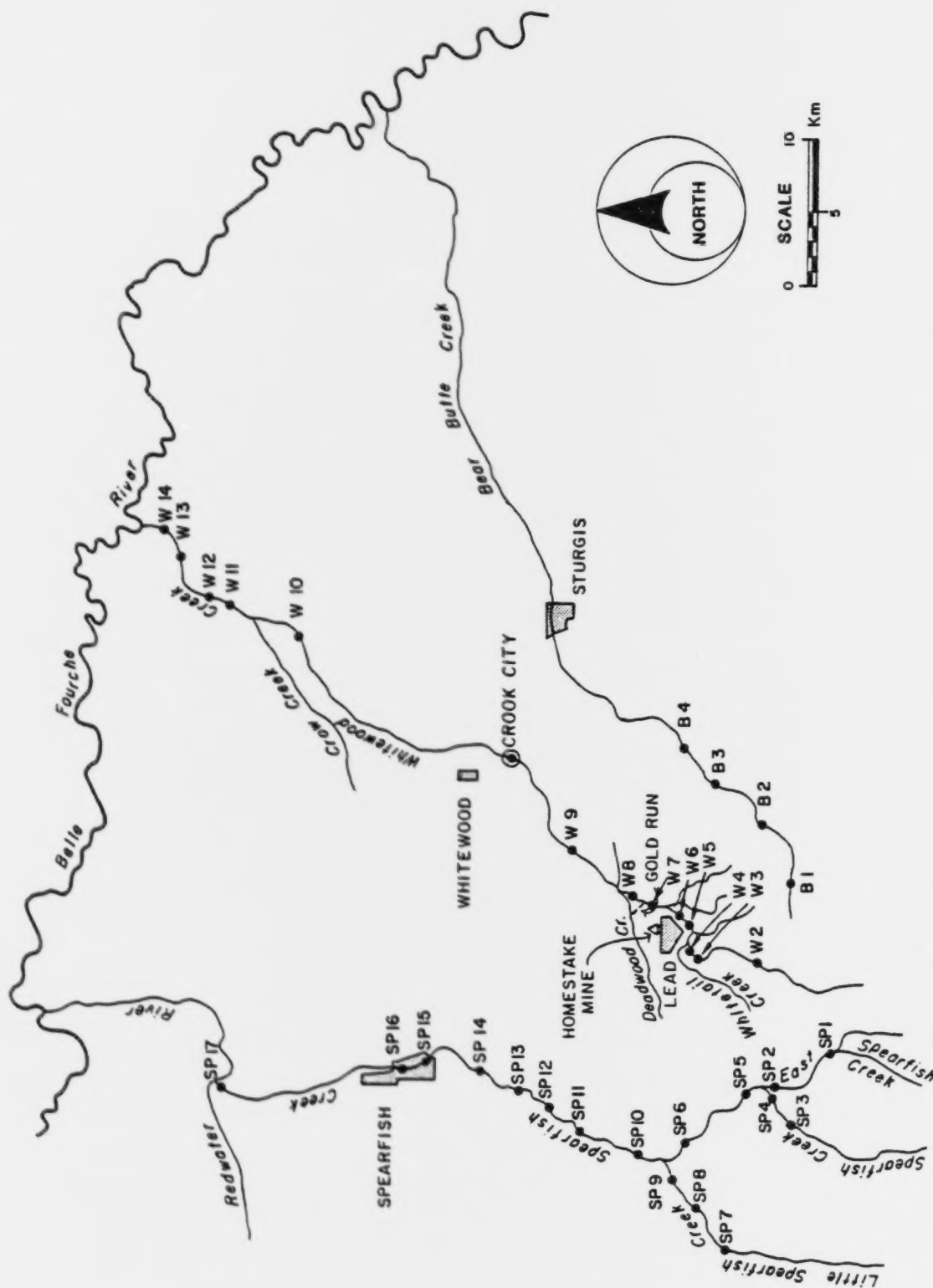
Fish

The fish community is dominated by brook trout from the headwaters to immediately upstream from Gold Run (station W7), the source of discharge from Homestake Mining Company (Figure 15 and Table 19). Only three other species were captured above Gold Run during Herricks' (1982) study: long-nose dace, green sunfish, and brown trout. Herricks proposed that this upper portion of Whitewood Creek was isolated by the Gold Run wastewater discharge which created a block to fish movement. Herricks felt this hypothesis was supported when creek chub larvae were captured at station W9, where fish had not been caught previously in the study, following water quality improvement. The improvement occurred due to reduced discharge from the Homestake Mining Company and high spring flows in 1982.

The brown and brook trout populations are wild and in 1981 were primarily composed of individuals less than 15.25 centimeters (6 inches) in length (Herricks, 1982). Factors which appeared to be limiting growth were low streamflow, which created large, shallow areas and high temperatures (Herricks, 1982). Trout were observed to be stressed by high temperature during the July 1981 sampling. Furthermore, an analysis of fish scales revealed that false annuli were commonly produced. False annuli can be related to stress and are produced when growth ceases (Herricks, 1982).

During the course of the study by Herricks (1982), fish were not caught downstream from station W5 except at station W14, the lowermost station near the confluence with the Belle Fourche River (Table 19). However, since the installation of the treatment process at the Homestake Mining Company in 1984, the water quality of Whitewood Creek has

FIGURE 15
FISH SAMPLING SITES



(MODIFIED FROM HERRICKS, 1982)

TABLE 19
SPECIES AND NUMBERS OF FISH CAUGHT PER 100 METERS IN RECENT STUDIES OF WHITEWOOD CREEK, SOUTH DAKOTA

SPECIES	W1	W2	W3	W4	W5	W6	W7	STATION							W14
								W8	W9	W10	W11	W12	W13		
March 1981								no fish	no fish	no fish	no fish	a/	--	--	
Brown trout (<i>Salmo trutta</i>)			2	19	2		7								
Brook trout															
Salvelinus fontinalis	90	42	150	121	26	26									
Long-nose dace															
Rhinichthys cataractae	2			2	1	1	1								
White sucker															
Catostomus commersoni															
Mountain sucker															
Catostomus platyrhynchus															
July 1981								no fish	no fish	no fish	no fish	--	--	--	
Brown trout		8	30	18	26	10	16								
Salmo trutta															
Brook trout															
Salvelinus fontinalis	19	173		370	373	78	43								
Long-nose dace															
Rhinichthys cataractae		1	10	1			8								
September 1981								no fish	no fish	no fish	no fish	--	--	--	
Brown trout															
Salmo trutta		14	1	2	11	20	2								
Brook trout															
Salvelinus fontinalis	9	188		91	404	182	60								
Long-nose dace															
Rhinichthys cataractae				1	1	1	86								2
Carp															
Cyprinus carpio															1
Creek chub															1
Semotilus atromaculatus															1
Lake chub															4
Couesias plumbeus															4
Flathead chub															4
Hybopsis gracilis															1165
Sand shiner															6
Notropis stramineus															350
Plains minnow															1
Hybognathus placitus															7
Fathead minnow															1
Pimephales promelas															1
White sucker															
Catostomus commersoni															
Mountain sucker															
Catostomus platyrhynchus															
Black bullhead															
Ictalurus melas															

(continued)

TABLE 19 (Continued)

SPECIES	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Stone cat														
<u>Noturus flavus</u>														6
<u>Plain killifish</u>														7
<u>Fundulus zebrinus</u>														1
<u>White bass</u>														1
<u>Morone chrysops</u>														1
<u>Black crappie</u>														1
<u>Pomoxis nigromaculatus</u>														1
<u>Green sunfish</u>														42
<u>Lepomis cyanellus</u>		1												
March 1982														
<u>Brown trout</u>	--		--					--	--	--	--	--	--	--
<u>Salmo trutta</u>		1												
<u>Brook trout</u>														
<u>Salvelinus fontinalis</u>		231		32	130	104	17							
<u>Long-nose dace</u>														
<u>Rhinichthys cataractae</u>		2					5							
July 1983														
<u>Creek shub</u>	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<u>Semotilus atromaculatus</u>														3
<u>Carp</u>														
<u>Cyprinus carpio</u>													4	3
<u>Fathead chub</u>														
<u>Hybopsis gracilis</u>													4	25
<u>White sucker</u>														
<u>Catostomus commersoni</u>														3
<u>Stone cat</u>														
<u>Noturus flavus</u>													8	7

a/ Indicates the station was not sampled

Source: Herricks, 1982.

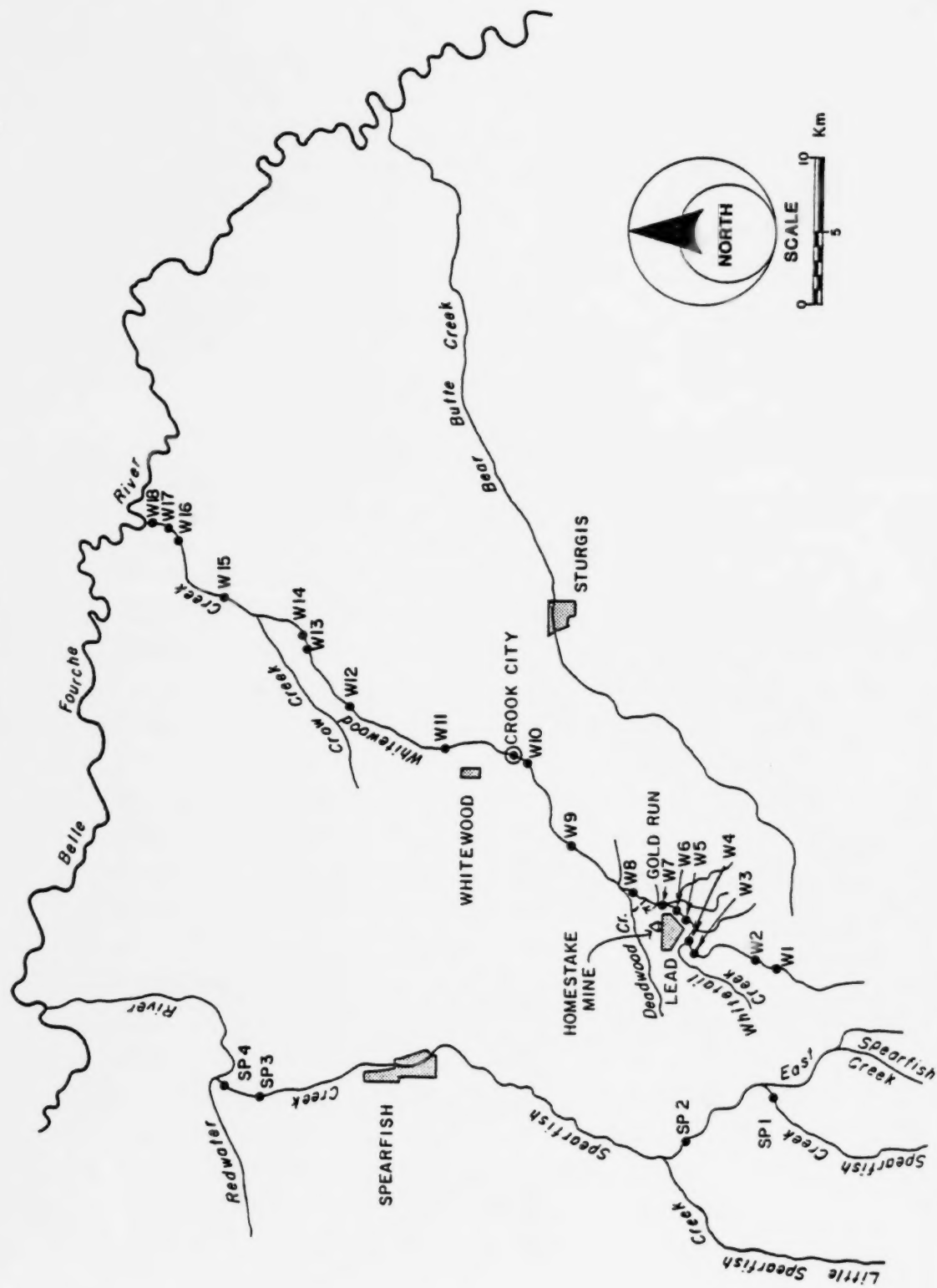
improved sufficiently to support a trout population. The stream segment downstream from Lead is stocked with catchable (20- to 25-centimeter or 8- to 10-inch-long) brown trout. However, it is fished only lightly because the public has not yet recognized that this segment is now capable of supporting fish life (R. Ford, South Dakota Department of Game, Fish and Parks, personal communication, 1986). The collection of fish species (shiners, chubs, sunfish, and bullheads) at station W14 is typical of a warm-water fish community of prairie streams. Warm water, primarily nongame, fish species were also captured in the lower reach of Whitewood Creek in 1983 by Fox Consultants, Inc. (1984) (Table 19).

Macroinvertebrates

Herricks (1982) identified a total of 262 macroinvertebrate taxa from Whitewood and Spearfish Creeks. Sampling was concentrated on Whitewood Creek with Spearfish Creek serving as a reference area. Sample locations are shown on Figure 16. Of the collected taxa, 93 were dipterans (flies) and 45 were coleopterans (beetles). The most abundant functional group was the collector-gatherers which gather particulate food materials (Table 20). Collector-filterers were a distant second in importance. These organisms also use particulate material, but they collect it with nets or body structures to filter the water. Shredders were found only in the upstream stations, which is a common pattern in streams. Shredders use coarse particulate material which enters the stream from the terrestrial environment and is an important food source to low-order, or headwater streams.

The macroinvertebrate assemblage was most diverse upstream from Gold Run (station W8). Particularly notable in the upstream area was the abundance of plecopteran (stonefly) species which were not observed downstream from Gold Run. Plecopterans are typically intolerant of pollution and prefer cold, fast, well-oxygenated water (Merritt and Cummins, 1984). The functional diversity of upper Whitewood Creek was consistently higher than that of other reaches and indicated a community of complex trophic relationships.

FIGURE 16
AQUATIC MACROINVERTEBRATE
SAMPLING SITES



(MODIFIED FROM HERRICKS, 1982)

TABLE 20
AVERAGE PERCENT OCCURRENCE OF AQUATIC MACROINVERTEBRATE FUNCTIONAL GROUPS
IN WHITEWOOD AND SPEARFISH CREEKS, SOUTH DAKOTA

FUNCTIONAL GROUP									
Station	Scraper	Filterer	Shredder	Predator	Collector-Gatherer	Collector-Filterer	Piercer-Parasite	General Predator ^{a/}	Unknown
Whitewood Creek									
W2	4.3	3.2	9.7	11.8	40.9	14.0	3.2	9.7	3.2
W3	4.1	0	12.2	13.3	35.7	13.3	3.1	15.3	3.1
W4	5.9	1.5	7.4	8.8	44.1	11.8	4.4	10.3	5.9
W5	6.9	0	8.3	11.1	30.6	16.7	4.2	16.7	5.6
W6	8.2	1.6	4.9	11.5	36.1	16.4	4.9	9.8	6.6
W7	7.0	1.4	9.9	11.3	32.4	16.9	4.2	11.3	5.6
W8	0	0	0	12.5	56.3	6.3	0	6.3	18.8
W9	0	0	0	0	73.9	8.7	0	8.7	8.7
W10	2.2	0	0	15.2	37.0	19.6	4.3	8.7	13.0
W14	1.7	0	0	6.4	46.8	25.5	4.3	8.5	6.4
W15	0.2	0	0	2.0	18.3	78.5	0	0	0
W16	2.1	0	0	6.4	46.8	25.5	4.3	8.5	6.4
Spearfish Creek									
SP1	0	4.1	10.8	0.1	40.5	10.8	4.1	16.2	5.4
SP2	3.1	3.1	9.4	15.6	40.6	9.4	3.1	9.4	6.3
SP4	9.1	1.8	1.8	10.9	38.2	12.7	3.6	16.4	5.5

^{a/} Herricks defined general predators as those organisms which are predaceous but supplemented their diet with plant and detrital material.

Sources: Herricks (1982) except Station W15 which is from Fox Consultants, Inc. (1984).

The Kirk Power Plant discharge from cooling tower blowdown appeared to exert periodic, temporary impacts on the macroinvertebrate community downstream from the discharge (Herricks, 1982). Station W5, below this discharge, was the only station upstream from Gold Run where plecopterans were not collected during one sampling visit (Herricks, 1982).

The Deadwood wastewater treatment effluent also affects the water quality at one station downstream (Herricks, 1982). This was indicated by the abundance of oligochaetes (worms) which are stimulated by large amounts of fine particulate organic matter.

Herricks (1982) concluded that the discharge from the Homestake Mining Company was clearly responsible for major changes in the macroinvertebrate community from station W8 to W15. From Gold Run to Crook City (W10), the number of taxa was considerably reduced (Table 21). Taxa collected at these stations were pollution-tolerant species such as Optioservus divergens (beetle), Coptotomus longulus (beetle), Deronectes striatellus (beetle), Tubifix tubifix (Oligochaete), Eiseniella tetraedra (oligochaete), Dixa sp. (fly), and Physa sp. (snail). Other widespread and tolerant species such as Baetis tricaudata (mayfly), Hesperophylax sp. (caddisfly) and Cheumatopsyche sp. (caddisfly) were found at most stations but not at the two immediately downstream from Gold Run. The three stations downstream from Gold Run (W8, W9, W10) had significantly fewer numbers of taxa but not numbers of individuals. Analyses indicated that the number of organisms and taxa were similar at the three stations downstream from Gold Run (W8, W9, W10). Often the number of organisms and taxa at these stations were statistically similar to Stations W10, W15, W16, W17, and W18 as well indicating that the effects of pollution extended downstream to the mouth of the creek. Stations W8 and W9 also exhibited groups of macroinvertebrates which were functionally similar. The diversity of functional groups was low at these two stations, indicating a lack of complex trophic linkages within the macroinvertebrate community (Table 22).

TABLE 21

NUMBER OF AQUATIC MACROINVERTEBRATE TAXA COLLECTED FROM WHITEWOOD AND SPEARFISH CREEKS, SOUTH DAKOTA
IN MARCH THROUGH DECEMBER, 1981 AND MARCH, 1982

Date	Whitewood Creek																Spearfish Creek			
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V14	V15	V16	V18	SP1	SP3	SP4			
March	--	39	26	29	28	23	20	4	9	9	17	--	--	--	29	42	--			
May	33	39	17	24	35	19	30	4	9	10	19	20	--	--	30	--	48			
July	--	36	21	12	21	22	18	18	16	22	25	22	25	20	17	26	46			
October	24	26	19	18	20	17	23	4	7	11	19	--	11	--	19	--	21			
December	23	40	38	29	34	27	30	3	5	8	21	24	18	--	32	35	55			
March	--	28	33	27	23	24	34	3	5	8	27	19	16	19	26	31	42			
Mean	27	35	26	23	27	20	26	6	8	11	21	16	18	19	25	33	42			

Source: Herricks, 1982

TABLE 22

DIVERSITY^{a/} OF AQUATIC MACROINVERTEBRATE FUNCTIONAL GROUPS
IN WHITEWOOD AND SPEARFISH CREEKS, SOUTH DAKOTA

<u>Station</u>	<u>March</u>	<u>July</u>	<u>October</u>	<u>March</u>
Whitewood Creek				
W2	1.65	1.50	1.58	1.79
W3	1.77	1.57	1.95	2.06
W4	1.45	1.45	1.41	1.11
W5	1.10	0.69	0.79	1.09
W6	0.99	1.02	0.92	1.24
W7	0.73	1.17	1.05	1.15
W8	0.05	0.13	0.06	0.07
W9	0.75	0.63	0.13	0.10
W10	0.39	1.35	1.71	1.63
W14	1.75	1.24	0.95	1.88
W16	--	1.17	1.28	1.94
Spearfish Creek				
SP1	1.90	1.67	1.68	1.72
SP2	1.73	--	--	--
SP3	--	--	--	1.67
SP4	1.90	1.67	1.68	1.72

a/ Shannon-Wiener Diversity Index.

Source: Herricks, 1982

The benthic community showed signs of recovery from pollution impacts starting near Crook City, but the creek also changes to a warm water habitat in this stretch. The lower stations W14, W15, W16, and W18, had a diverse assemblage of warm water macroinvertebrates. Odonata (dragonflies), trichoptera (caddisflies), diptera (flies) and coleoptera (beetles) became prevalent but their numerical contribution to the assemblage differed among these stations. In this segment, numbers of taxa were greatest at station W14 (see Table 21), possibly due to a more varied substrate (Herricks, 1982). The functional diversity of lower Whitewood Creek approached or equaled that of the community upstream from Gold Run (see Table 22), but the trophic structure was different. No filterers or shredders were downstream from Gold Run because less coarse particulate material was present in the stream. The proportion of collector-filterers was greatest at the downstream stations, indicating a greater amount of fine particulate material in the stream (Table 20). These observations are expected with a downstream progression. Herricks (1982) concluded that the warm water zone of Whitewood Creek was substantially improved but not completely recovered from upstream municipal and industrial wastewater impacts.

Metals Accumulation in Macroinvertebrates

Composite macroinvertebrate samples from contaminated stream reaches had higher mean concentrations of some metals than the composite macroinvertebrate sample from uncontaminated reference streams (Belle Fourche River above Whitewood Creek, Spearfish Creek, and False Bottom Creek) according to sampling and analyses performed by Fox Consultants, Inc. (1984). In the contaminated areas of Whitewood Creek and the Belle Fourche River (below Whitewood Creek) macroinvertebrate samples had higher mean concentrations of arsenic, cadmium, copper, iron, manganese, mercury, nickel, and silver (Table 23). However, only arsenic, selenium, and silver values were statistically higher. The most notable differences were apparent for arsenic (where contaminated areas had a mean concentration approximately 60 times greater than the reference station mean), cadmium (about 4 times greater), and copper

TABLE 23
COMPARISON OF MEAN METAL CONCENTRATIONS IN THE
COMPOSITE MACROINVERTEBRATE SAMPLES FROM CONTAMINATED
AND REFERENCE STATIONS

<u>Metal</u>	<u>Mean Concentration (mg/kg)</u>	
	<u>Contaminated Stations^{a/}</u>	<u>Reference Stations^{a/}</u>
Arsenic	61 ± 38	1 ± 0.1
Cadmium	0.8 ± 0.7	0.2 ± 0.1
Chromium	1.0 ± 1.4	0.9 ± 0.7
Copper	22 ± 13	8.0 ± 2.4
Iron	1166 ± 508	669 ± 526
Lead	1.5 ± 0.7	1.4 ± 0.8
Manganese	133 ± 55	102 ± 70
Mercury	<0.09 ± 0.05	<0.02 ^{c/}
Nickel	3.4 ± 4.7	1.6 ± 1.2
Selenium	<0.5 ^{b/}	0.9 ± 0.2
Silver	0.3 ± 0.1	ND ^{c/}
Zinc	29 ± 8	31 ± 12

a/ Contaminated stations are Whitewood Creek Stations W10, W11, W12, W13, W14, W15, W17, W18, and the Belle Fourche River below Whitewood Creek on the Belle Fourche River; Spearfish Creek Station SP3, and a site on False Bottom Creek, a tributary to the Redwater River.

b/ Based on one value.

c/ Not detected.

Source: Fox Consultants, Inc. (1984).

(about 2.8 times greater). Silver was reported from seven of nine invertebrate samples from the contaminated stations, but was not reported from any reference station samples. Mercury was reported from six of nine invertebrate samples from the contaminated stations and from only one of the three reference station samples. The mean selenium concentration was higher in reference stream macroinvertebrates (0.9 mg/kg) than in the contaminated stream macroinvertebrates (0.5 mg/kg). There were no apparent differences in chromium, zinc, and lead concentrations between reference stream and contaminated stream sections. Composite macroinvertebrate samples taken from stations with high metal concentrations in the sediments generally tended to have higher concentrations of the same metals. The trend, however, was not consistent for all metals and all stations. The most notable examples of the trend were arsenic, copper, iron, and manganese. The highest macroinvertebrate arsenic levels occurred at W13, W14, W15, and W17.

Spearfish Creek

Spearfish Creek is a relatively unimpacted stream that has been used as a reference stream in studies by Herricks (1982) and Fox Consultants, Inc. (1984). Two major stream diversions occur upstream from the town of Spearfish for hydropower generation. One diverts water about 1.5 kilometers (1 mile) upstream from the confluence with Little Spearfish Creek and releases it back to the stream about 8 kilometers (5 miles) downstream. The other diverts water from just downstream from Squaw Creek and releases it back to the stream near the town of Spearfish. This river segment is normally dewatered even without diversions as the stream flows into the Pahasapa Limestone.

The gradient of Spearfish Creek is about 2 percent in the intermediate reaches, which is similar to the gradient of the intermediate reaches of Whitewood Creek (see Table 17). Based on the data from those reaches where the substrate was sampled, Spearfish Creek appears to have fewer boulders and a more even distribution of rubble, gravel, and sand over its bottom than Whitewood Creek (see Table 18). The

large amount of embeddedness is due to a travertine coating from spring water high in dissolved solids (Herricks, 1982). Its banks are stable and covered with trees at stations SP1 and SP2 (see Figure 14).

Fish

The fish community is dominated by brown trout (Table 24). Brook trout, white suckers and long nose dace are other members of the community. Upper Spearfish Creek (SP3, SP4, SP5, SP6, SP10, SP11), East Spearfish Creek (Hannah Creek) (SP1 and SP2), and Little Spearfish Creek (SP7, SP8, SP9) were populated by brown trout less than 8 inches in length (Table 25). A catch-and-release fishing regulation exists on East Spearfish Creek. At station SP10 nearly half the captured fish were longer than 8 inches.

Catchable brown trout are stocked primarily in the town of Spearfish (stations SP15 and SP16), which accounts for the larger fish at these stations. These fish would only be able to migrate upstream during spring runoff because at other times the stream segment from Rubicon Gulch to Spearfish is dry. Limited stocking is performed upstream from Rubicon Gulch, and is probably responsible for the larger number of 23-centimeter (9-inch) trout at stations SP10, SP12 and SP13. Except for this limited stocking and possible migrants from the Sturgis area during high water, the trout population upstream from SP14 is sustained by natural reproduction.

Stream improvement consisting of wing deflectors, has been performed by South Dakota Division of Wildlife. These, in conjunction with catch and release regulations at stations SP12 and SP13, which probably enhance the maintenance of larger fish in this stream stretch. Station SP14 is actually in a segment of the creek which has nearly been dewatered. Apparently some pools remain to permit survival of small fish.

Macroinvertebrates

The high numbers and diversity of macroinvertebrates from upper and lower Spearfish Creek indicate that there is no impairment of water quality or habitat (see Figure 16 and Tables 20 and 22). The assem-

TABLE 24

SPECIES AND NUMBERS OF FISH CAUGHT PER 100 METERS IN RECENT STUDIES OF SPEARFISH CREEK, SOUTH DAKOTA

SPECIES	STATION																
	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	SP9	SP10	SP11	SP12	SP13	SP14	SP15	SP16	SP17
March 1981 ^{a/}																	
Brown trout																	
Salmo trutta				275													
Brook trout																	
Salvelinus fontinalis				4													
July 1981 ^{a/}																	
Brown trout																	
Salmo trutta				372													
Brook trout																	
Salvelinus fontinalis				20													
September 1981 ^{a/}																	
Brown trout																	
Salmo trutta				32													
White sucker																	
Catostomus commersoni				25													
March 1982 ^{a/}																	
Brown trout																	
Salmo trutta				451													45
Brook trout																	1
Salvelinus fontinalis				15													71
Long-nose dace																	8
Rhinichthys cataractae																	
White sucker																	
Catostomus commersoni																	
July 1985 ^{b/}																	
Brown trout																	
Salmo trutta	118	252	348	414	400	369	14	2	452	329	284	206	302				
Brook trout																	
Salvelinus fontinalis	1	83	53	2	2		1	27	7			2	5				
Rainbow trout																	
Salmo gairdneri											1	66	84				
August 1985 ^{b/}																	
Brown trout																	
Salmo trutta																	414
October 1985 ^{b/}																	
Brown trout																	
Salmo trutta																	209
Rainbow trout																	191
Salmo gairdneri																	2

^{a/} Source: Herricks, 1982.^{b/} Source: South Dakota Game, Fish, and Parks Department, 1986.

TABLE 25

PERCENTAGE OF THE TROUT POPULATION IN SPEARFISH CREEK
GREATER AND LESS THAN 20 CENTIMETERS (8 INCHES) IN LENGTH

Station	Species	Percent Less Than 20 cm	Mean Length of < 20 cm Group	Percent Greater Than 20 cm	Mean Length of > 20 cm Group
SP1	Brown trout	83	5	17	9
SP2	Brown trout	86	5	14	9
SP3	Brown trout	90	5	10	9
SP4	Brown trout	98	5	2	8
SP5	Brown trout	74	6	26	9
SP6	Brown trout	71	5	29	9
SP7	Brown trout	79	7	21	9
SP8	Brook trout	97	6	3	8
SP9	Brown trout	92	6	8	9
SP10	Brown trout	51	6	49	9
SP11 ^{a/}	Brown trout	73	6	27	9
SP12	Brook trout	48	6	52	9
	Brook trout	100	5		
	Rainbow trout	80	5	20	9
	Brown trout	21	6	69	9
	Brook trout	100	6		
	Rainbow trout	53	6	47	9
SP13	Brown trout	46	6	54	9
	Rainbow trout	80	4	20	9
SP14 ^{b/}	Brown trout	94	6	6	9
SP15	Brown trout	62	4	38	11
	Brown trout	58	6	42	10
	Brown trout	65	6	35	10
	Brown trout	66	6	34	10
SP16 ^{c/}	Brown trout	51	6	49	10
	Brown trout	66	6	44	9

a/ Two electrofishing efforts were conducted at this station.

b/ Four electrofishing efforts were conducted at this station.

c/ Two electrofishing efforts were conducted at this station.

Source: South Dakota Department of Game, Fish, and Parks, 1986.

blage of organisms collected at station SP1 was similar to those collected at stations W1, W2, and W4 in the Whitewood Creek drainage. Collector-gatherers dominated the benthic community at all the sampling sites (Table 20). Collector-filterers and predators collectively made up 20 to 30 percent of the community at the sampling sites. Filterers were somewhat more important in Spearfish Creek than in Whitewood Creek. Shredders maintained representatives in the benthic community at upper and lower sites in Spearfish Creek but were not found in Whitewood Creek below W8. This indicates that Spearfish Creek receives terrestrial material such as leaves from the riparian area throughout its length. Herricks (1982) did not discuss the taxa of Spearfish Creek, but Fox Consultants, Inc. (1984) described the proportion of macroinvertebrate families found in the benthic community at SP3. Hydropsychidae (caddisfly), Baetidae (mayfly), and Perlodidae (stonefly) comprised 37, 30, and 11 percent, respectively, of the collection. Elmidae (beetles) and Chironomidae (midges) made up 8 percent of the collection. This assemblage, particularly with the good representation of stoneflies and high functional diversity (Table 22), indicates a healthy stream free of major disturbances even in its lower reach.

Bear Butte Creek

Bear Butte Creek from its headwaters to Boulder Canyon is a small, high-gradient stream with substantial canopy cover. Its substrate is dominated by rubble and gravel and the riparian vegetation consists of pine and spruce forest with an understory of shrubs and thick grass. In the upper reaches, several beaver dams create pools. The site inspection suggested some impact by mine drainage from Strawberry Creek and drainage from a mine near Galena may exist, but water quality analyses (EPA STORET data base) did not reveal any contamination of concern. Precipitated organic material was also observed upstream from Strawberry Creek during the site inspection. This may originate from a small resort which offers trout fishing in a stocked pond and will fry customers' catches.

Fish sampling of Bear Butte Creek at four locations by South Dakota Division of Wildlife (Figure 15) produced four species of nongame fish in low densities (Table 26). However, wild brown and brook trout populations are known to exist in the creek (R. Ford, South Dakota Department of Game, Fish and Parks, personal communication, 1986). Bear Butte Creek upstream from Boulder Canyon where it sinks into the Pahasapa Limestone is isolated from fish populations downstream from Boulder Canyon, which could otherwise populate the upper portions of the creek. Bear Butte Creek was stocked in April and June 1986 east of Sturgis with 700 catchable (20- to 25- centimeter or 8- to 10-inch-long) brown trout.

SOCIOECONOMICS

The description of the affected environment for socioeconomics begins with a brief comparative analysis of key socioeconomic factors. The geographic focus of this comparative analysis is a three-county region containing Lawrence, Meade, and Pennington Counties, which are linked by a number of economic, historical, and governmental/institutional ties. Comparative data for South Dakota is also presented to provide another comparative perspective.

Following the regional overview, the focus of the discussion narrows to Lawrence County and the communities and surrounding environs of Lead and Deadwood. This geographic area encompasses the locations of existing and future gold deposit exploration and mining activity, as well as the primary area of influence for potential socioeconomic impacts. The descriptions are based on secondary data sources, personal observations in the area and discussions with local government officials and residents.

Finally, a site-specific description of each of the three drainages identified for detailed analysis is provided. These descriptions include discussions of the amount and type of development, land use and ownership and recreation use occurring in the area.

TABLE 26

SPECIES AND NUMBERS OF FISH CAUGHT PER 100 METERS
IN RECENT STUDIES OF BEAR BUTTE CREEK, SOUTH DAKOTA

SPECIES	STATION			
	B1	B2	B3	B4
September 1984				
Long-nose dace				
<u>Rhinichthys cataractae</u>			2	
Mountain sucker				
<u>Catostomus platyrhynchus</u>			7	
White sucker				
<u>Catostomus commersoni</u>			1	
June 1985				
Long-nose dace				
<u>Rhinichthys cataractae</u>	no fish	"numerous dace"		65
Mountain sucker				
<u>Catostomus platyrhynchus</u>				3
White sucker				
<u>Catostomus commersoni</u>				58
<u>"unknown minnow"</u>				1

Source: South Dakota Department of Game, Fish and parks (1986)

Regional Overview

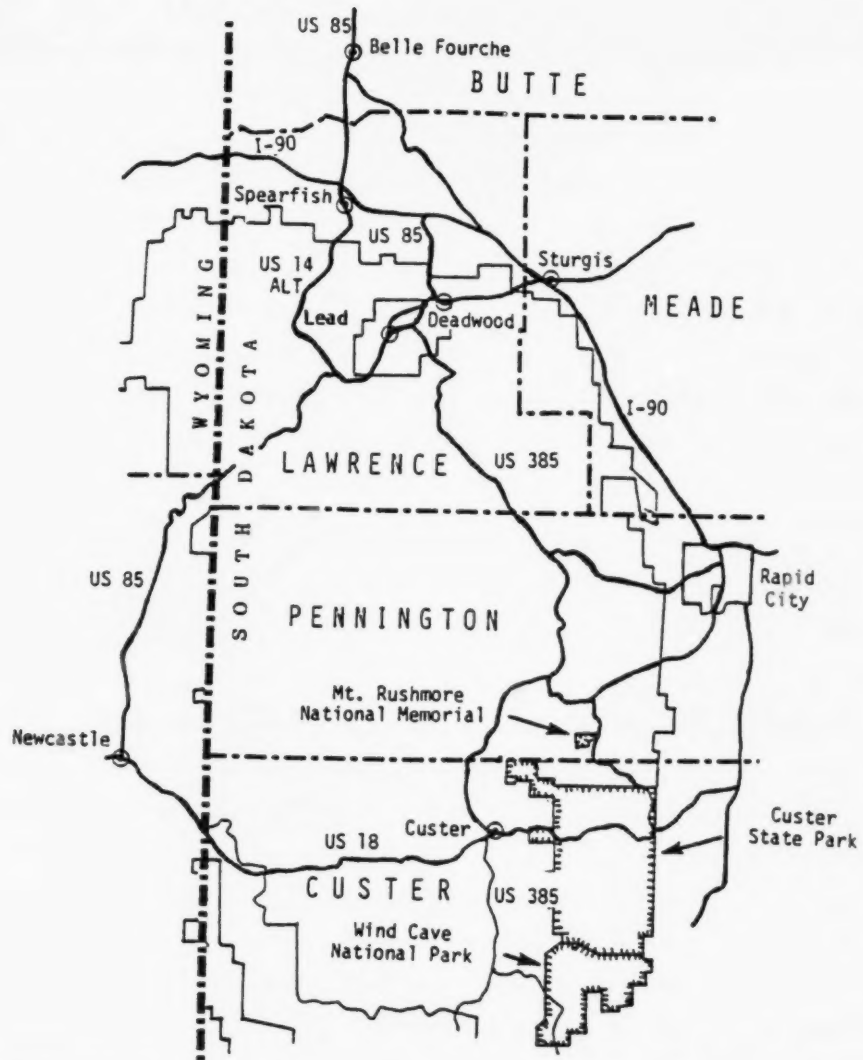
Lawrence County is located in the extreme west-central part of the State, sharing its western boundary with Wyoming and lying midway between South Dakota's northern and southern boundaries. Contiguous to Lawrence County are Butte, Meade, and Pennington Counties; the latter is also equivalent to the Rapid City Metropolitan Statistical Area (Figure 17). The four counties are part of a seven-county area comprising the Black Hills Council of Local Governments (BHCLG), a regional planning and service agency.

In the following discussion, however, selected socioeconomic data are provided for only Lawrence, Meade, and Pennington Counties with emphasis focused on Lawrence County. Historical and present economic, social and political links between these counties provide a common denominator. Yet, at the same time there is a substantial amount of variation in socioeconomic factors among the three counties, which must be understood in order to evaluate the potential impacts of future mining activity in the region.

In its earliest period of economic development, the Black Hills region attracted settlers and prospectors interested in exploiting the natural resources of gold and other minerals, and in farming. The first recorded evidence of the area's rich mineral deposits occurred in 1834, with a find by a group of seven individuals. However, after discovering gold, the party was apparently killed by the Indian inhabitants of the area. Subsequently, over forty years passed until the Gold Rush of 1876 brought thousands of prospectors and settlers to the area, forever changing its future (Brady and Chichester, 1969). Since the postwar period, the economic base of the region has expanded, although some parts of the region, such as Lawrence County, continue to rely heavily on mining or agriculture.

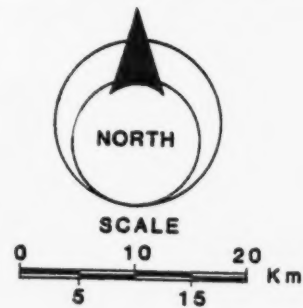
Growth in government, trade, services, and manufacturing over the last half-century has resulted in a moderate level of diversification in the Black Hills Region economy. The location of the Ellsworth Air Force Base 13 kilometers (8 miles) east of Rapid City, as well as other

FIGURE 17
SOCIOECONOMIC FEATURES



LEGEND

- COUNTY BOUNDARIES
- ~~~~~ NATIONAL AND STATE PARKS AND MEMORIALS
- ~~~~~ BLACK HILLS NATIONAL FOREST
- MAJOR HIGHWAYS



Federal government agencies throughout the region, has pumped millions of dollars into the local economy. Construction of Interstate 90 and the growth of population centers in the western north-central United States have enhanced the function of the Rapid City metropolitan statistical area as a trade and service center for western South Dakota and surrounding areas of Wyoming, Montana, North Dakota, and Nebraska. Also, the numerous regional tourist attractions, including the Mount Rushmore National Memorial, Badlands National Monument, Wind Cave National Park, and Jewel Cave National Monument have fueled the growth of the local tourist industry (Black Hills Council of Local Governments, 1984). Furthermore, a substantial portion of the lands within the region, including over one-half of Lawrence County, are Federal lands administratively designated as part of the Black Hills National Forest. The forest supports a variety of recreation, timber harvesting, mining and other multiple-use activities (U.S. Forest Service, 1983a).

Population

Table 27 compares population trends for Lawrence County with its neighboring counties and the entire State for the period 1960 to 1984. As shown, population growth within the three counties has consistently exceeded that experienced by the State as a whole. While the statewide population declined between 1960 and 1970, all three counties experienced population increases. From 1970 to 1980, the combined population growth of the region accounted for nearly 62 percent of the statewide growth. Based on the 1984 population estimates, the disproportionate growth trends are continuing, with 40 percent of the statewide growth accounted for by the changes in this region.

As shown in Table 27, Lawrence County, with an estimated 19,200 residents in 1984, currently ranks seventh of the 66 counties in South Dakota with respect to population. Between 1970 and 1980, the county's population increased less rapidly than that of its neighbors and only slightly faster than the state as a whole. Since 1980, Lawrence,

County's population has grown at a faster rate than that of either the State's or Meade County but slower than that of the more urbanized Pennington County.

TABLE 27
POPULATION TRENDS IN BLACK HILLS REGION COUNTIES

	<u>1960</u>	<u>1970</u>	<u>1980</u>	<u>1984</u>	<u>1984 State Rank</u>	<u>Compound Percent 1970-80</u>	<u>Annual Change 1980-84</u>
South Dakota	680,514	665,507	690,786	705,800	--	0.3	0.5
Lawrence County	17,075	17,453	18,339	19,200	7th	0.5	1.2
Meade County	12,044	17,020	20,717	21,500	6th	2.0	0.9
Pennington County	58,195	59,349	70,361	74,700	2nd	1.7	1.5

Source: U.S. Bureau of Economic Analysis, 1986a; U.S. Bureau of the Census, 1982.

Employment

Since 1970, both statewide and regional employment trends have generally coincided with the growth in population, increasing constantly over the period (Table 28). However, the relative growth in employment has been substantially higher than the population growth; for example, total employment in Pennington County increased by nearly 5,200 jobs between 1980 and 1984, compared to a population growth of only 4,340 persons. Although not as dramatic, similar trends of disproportionate employment growth have occurred in both Lawrence and Meade Counties, as well as statewide, since 1970. The primary causes for these differences are a general increase in the labor force participation rates among the adult population and the declining average household size. Both of these factors tend to increase the employment to population ratios.

TABLE 28
EMPLOYMENT TRENDS IN BLACK HILLS REGION COUNTIES

	<u>1970</u>	<u>1980</u>	<u>1984</u>	<u>Compound Annual Percent Change</u>	
				<u>1970-1980</u>	<u>1980-1984</u>
South Dakota	296,679	348,993	359,252	1.6	0.8
Lawrence County	6,352	8,639	8,992	3.6	1.0
Meade County	4,289	5,439	5,745	2.7	1.4
Pennington County	29,338	42,255	47,443	4.4	3.1

Source: Bureau of Economic Analysis, 1986a; U.S. Bureau of the Census, 1982.

Growth in employment in Lawrence County has kept pace with growth in population over the 1980 to 1984 period. However, total employment has not grown as quickly in Lawrence County as in its neighboring counties, although the absolute change of 300 to 400 jobs was comparable in Lawrence and Meade Counties. The strong growth in Pennington County reflects its expanded role as a regional trade and service center, especially for the surrounding energy development regions of Wyoming, Montana, and North Dakota, and the increasing diversification of its economic base into manufacturing (L. Meredith, Black Hills Council of Local Governments, personal communication, 1986). Employment growth in Lawrence and Meade Counties has been led by increased service sector employment catering to the local tourism and recreation industries.

As is also evident from Table 28, employment growth between 1980 and 1984 has slowed considerably since the 1970 to 1980 period, when average annual growth rates ranged between 2.7 and 4.4 percent. These changes have been brought about as a result of a stabilization or decline of other traditional growth sectors of the local economy, especially government and mining.

Personal Income

The distribution of personal income earnings in each of the three counties and the state is shown for 1984 in Table 29. In both Pennington County and South Dakota, the services sector provides the highest

TABLE 29

COMPOSITION OF TOTAL PERSONAL INCOME,
FOR BLACK HILLS COUNTIES AND SOUTH DAKOTA, 1984

PERSONAL INCOME BY SOURCE: (thousands of dollars)	South Dakota		Lawrence County		Meade County		Pennington County	
	Amount	Percent of Total	Amount	Percent of Total	Amount	Percent of Total	Amount	Percent of Total
Total Earnings by 1 Place of Work	\$5,134,942		\$135,737		\$ 77,442		\$707,608	
Adjustments for Non-earnings income	2,561,178		63,706		134,529		149,208	
Total Personal Income by Place of Residence	\$7,696,120		\$199,443		\$211,971		\$856,816	
PER CAPITA PERSONAL INCOME:	\$ 10,904		\$ 10,400		\$ 9,845		\$ 11,465	

EARNINGS OF PLACE OF WORK BY INDUSTRY:
(thousands of dollars)

	South Dakota		Lawrence County		Meade County		Pennington County	
	Amount	Percent of Total	Amount	Percent of Total	Amount	Percent of Total	Amount	Percent of Total
Farm	\$ 828,274	16.1	\$ 4,362	1.7	\$13,739	17.7	\$ 13,847	2.0
Nonfarm	4,306,668	83.9	13,376	98.3	63,703	82.3	693,761	98.0
Private	3,356,808	65.4	114,003	84.0	36,379	47.0	476,810	67.4
AFPO ^a	26,341	0.5	76	0.1	(D)	--	1,437	0.2
Mining	79,744	1.6	53,264	39.2	(D)	--	7,911	1.1
Construction	245,042	4.8	5,255	3.9	4,282	5.5	50,997	7.2
Manufacturing	556,436	10.8	12,361	9.1	5,591	7.2	63,744	9.0
TCU ^c	364,177	7.1	5,384	4.0	2,693	3.5	51,538	7.3
Wholesale Trade	359,638	7.0	3,492	2.6	3,815	4.9	41,980	5.9
Retail Trade	526,393	10.3	13,276	9.8	6,596	8.5	89,324	12.6
FIRE ^d	273,990	5.3	3,552	2.6	1,884	2.4	31,298	4.4
Services	925,047	18.0	17,343	12.8	10,493	13.5	138,586	19.6
Government	949,860	18.5	19,372	14.3	27,324	35.3	216,951	30.7
Federal, Civilian	238,440	4.6	3,635	2.7	18,178	23.5	37,124	5.2
Military	137,785	2.7	590	0.4	522	0.7	117,603	16.6
State and Local	573,635	11.2	15,147	11.2	8,624	11.1	62,224	8.8
Total Earnings by Place of work	\$5,134,942	100.0	\$135,737	100.0	\$77,442	100.0	\$707,608	100.0

(Continued)

TABLE 29 (Continued)

Note: For each location, only the sectors accounting for the greatest shares of local personal income are included.

a/ Agricultural Service, Fishing and Other

b/ (D) - data not reported to prevent disclosure of confidential information. Total employment within the two industries is 115 or 2.0 percent of the total.

c/ Transportation, Communication, and Utilities.

d/ Finance, Insurance, and Real Estate.

Source: U.S. Bureau of Economic Analysis, 1986.

share of income earnings. Services is the single largest employment sector in both these areas. Meade County is most heavily dependent on the Federal civilian government employment as a source of personal income; this sector provides about 23.5 percent of the county's total income compared to only 12.5 percent of total county employment. In Lawrence County, a very large share of all personal income is generated by the mining industry. The total mining earnings of over \$53 million in 1984 accounted for nearly \$4.00 of every \$10.00 earned in the county. Yet, only about 18 percent of the total employment occurs in this sector.

The three counties also show some variation in per capita income earnings. In 1984, residents of Pennington County, with an average of \$11,468, enjoyed the highest per capita incomes in the area. In Lawrence County, per capita incomes were considerably lower, averaging \$10,400. This was also below the average income in the State that year of \$10,904. Meade County residents had even lower average incomes of \$9,845 per capita.

Unemployment

Average unemployment rates in South Dakota and in the three-county Black Hills region have been low relative to national jobless rates during the 1980 to 1985 period, as shown in Table 30. Within the region, there have been some differences among the counties' rates, but these have been relatively minor. Still, unemployment in Lawrence County has tended to be slightly higher than in Meade and Pennington counties or the State.

TABLE 30
AVERAGE ANNUAL UNEMPLOYMENT RATES IN BLACK HILLS
REGION COUNTIES, SOUTH DAKOTA, AND THE UNITED STATES

	Percent of the Labor Force Unemployed					
	1980	1981	1982	1983	1984	1985
United States	7.1	7.6	9.7	9.6	7.5	7.1
South Dakota	4.8	5.1	5.5	5.4	4.4	5.2
Lawrence County	5.1	5.0	6.1	5.3	4.8	5.4
Meade County	5.1	4.4	4.8	5.5	3.5	4.4
Pennington County	5.6	5.0	5.1	5.1	4.3	5.3

Source: U.S. Bureau of Economic Analysis, 1986b.

Economic Base

There are both similarities and differences among the three counties with respect to composition of the economic base. The similarities stem from common economic links to tourism, outdoor recreation, timbering/lumber and wood processing and the Federal government. Natural resource availability, transportation networks and local community roles as trade and service centers account for many of the differences.

As shown in Table 31, all three counties have relatively high proportions of employment in the services, retail trade and manufacturing industries. These industries encompass the types of business associated with tourism and lumber and wood processing. Although the share of Meade County's total employment appears to be below the levels in the other counties or the state, it is in fact comparable to that for the other jurisdictions if only nonfarm employment is considered; the high percentage of farm employment skews the proportion in the nonfarm industries. The importance of tourism in the local economies is illustrated by the high share of total employment in retail trade and services and by a recent study which revealed that total visitor-related spending accounted for about 18 percent of all taxable sales in Lawrence and Pennington counties between September 1983 and August

TABLE 31
COMPOSITION OF EMPLOYMENT FOR BLACK HILLS REGION COUNTIES, 1984

	South Dakota		Lawrence County		Meade County		Pennington County	
	Employment	Percent of Total	Employment	Percent of Total	Employment	Percent of Total	Employment	Percent of Total
By Industry:								
Farm	46,868	13.0	269	3.0	923	16.1	661	1.4
Nonfarm	312,374	87.0	8,723	97.0	4,822	83.9	46,782	98.6
Private	248,478	69.2	7,251	80.6	3,322 b/	57.8	34,184	72.1
AFPO	3,559	1.0	158	1.8	(D)	1.0	313	0.7
Mining	3,207	0.9	1,731	18.1	(D)	1.0	526	1.1
Construction	15,704	4.4	379	4.2	289	5.0	2,745	5.8
Manufacturing	30,264	8.4	710	7.9	375	6.5	3,959	8.3
TCU	15,232	4.2	270	3.0	159	2.8	2,130	4.5
Wholesale trade	18,422	5.1	204	2.3	183	3.2	2,000	4.2
Retail Trade	61,030	17.0	1,590	17.7	855	14.9	8,802	18.6
FIRE	21,090	6.2	418	4.6	247	4.3	2,933	6.2
Services	79,151	22.0	1,891	21.0	1,099	19.1	10,776	22.7
Government	63,896	17.8	1,472	16.4	1,500	26.1	12,598	26.6
Federal, Civilian	10,436	2.9	169	1.9	716	12.5	1,622	3.4
Military	10,710	3.0	121	1.3	112	1.9	6,743	14.2
State & Local	42,750	11.9	1,182	13.1	672	11.7	4,233	8.9
TOTAL EMPLOYMENT	359,252	100.0	8,992	100.0	5,745	100.0	47,443	100.0

a/ Agricultural Service, Forestry, Fishing, and Other.

b/ (D) - data not reported to prevent disclosure of confidential information. Total employment within the two industries is 115 or 2.0 percent of the total.

c/ Transportation, Communication, and Utilities

d/ Finance, Insurance, and Real Estate

Source: U.S. Bureau of Economic Analysis, 1986a.

1985. During the same period, one-eighth (12.5 percent) of all taxable sales in Meade County was attributed to visitor-related spending (University of South Dakota, 1986).

As also shown in Table 31, some dissimilarities exist. Retail and service employment, while high in all counties, was especially high in Pennington County. This is due to the role of Rapid City as a regional trade and service center serving the western half of South Dakota and parts of four neighboring states.

Employment in Lawrence County is much more highly concentrated in the mining industry than either of its neighbors or the state as a whole. The local mining sector accounts for 18 percent of all local jobs in Lawrence County and over half of the total mining jobs in the state, compared to 2 percent or less in Meade and Pennington counties and South Dakota. The majority of these jobs are associated with the Homestake Mining Company's operations based in Lead. More recently, employment at Homestake has declined, but some of the decline was offset by other mining exploration and development operations in Lawrence County, for example, Wharf Resources heap leach operation southwest of Lead, which employs about 100 persons (Mountain International, Inc., 1985; H. Scholz, Wharf Resources, Ltd., personal communication, 198).

In contrast to the dependence on mining in Lawrence County, the economies of both Pennington and Meade Counties are more heavily concentrated in Federal government employment. Ellsworth Air Force Base, a strategic military facility serving as a base for part of the nation's long-range B-52 and B-1 bomber fleets, is located in northern Pennington County, near the Meade County border. Meade County hosts a major Veteran's Administration Hospital, providing substantial Federal civilian employment.

As mentioned earlier, the other primary difference in local economic composition is the concentration of farming employment in Meade County, accounting for over 16 percent of the total local employment. Although the extent of local impacts associated with the current nationwide agriculture crisis is uncertain, farming in Meade County

had been bucking national trends. According to the 1982 Census of Agriculture, when the number of farms and acreage in farm lands declined nationally and in the state between 1978 and 1982, both increased in Meade County. Total acreage of land in farms in Lawrence and Pennington Counties declined during the same five-year period (U.S. Bureau of the Census, 1982).

Tourism and Recreation

As previously mentioned, tourism and recreation have important roles in the local economy. Natural and man-made features and recreational opportunities abound in the region. These include public sites, such as the Mt. Rushmore National Monument, national and state parks and the Black Hills National Forest, as well as the historical gold mining districts of Lead, Deadwood and Custer. Numerous streams and lakes, as well as developed Forest Service picnic areas and campgrounds help support the region's tourism industry and provide recreation opportunities for area residents over much of the year. Among the more popular activities are hunting primarily for deer and game birds, fishing, hiking, camping and 4-wheel drive touring on the many mining and logging roads throughout the area (U.S. Forest Service, 1983a; P. Mock, Black Hills National Forest, personal communication, 1986).

Tourism in the three county region is based primarily on visits to a number of natural and historical sites rather than on business or convention related trips. Information on annual numbers of visits to five major sites in the area is shown for three recent years in Table 32. As is indicated, the number of visits to each of the individual sites has fluctuated over the 1983 to 1985 period. Changes in the number of visitors range from an increase of 44 percent at Jewel Cave to a decrease of over seven percent at Badlands National Monument. However, the importance of tourism is obvious as combined annual visits to the sites in the region have totaled over five million for each of the years between 1983 and 1985 and the number of visits has increased nearly two percent.

TABLE 32
NUMBER OF ANNUAL VISITS TO SELECTED REGIONAL TOURIST
SITES IN SOUTHWESTERN SOUTH DAKOTA

	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>1983-1985</u> <u>Percent Change</u>
Badlands (Pennington County)	1,038,981	1,125,675	962,242	-7.4
Jewel Cave (Custer County)	89,645	102,000	129,076	44.0
Mount Rushmore (Pennington County)	1,983,710	1,886,790	2,112,281	6.5
Wind Cave (Custer County)	1,015,144	1,037,735	963,811	-5.1
Custer (Custer County)	<u>1,022,553</u>	<u>994,418</u>	<u>1,072,907</u>	4.9
TOTAL	5,150,033	5,146,618	5,240,317	1.8

Source: State of South Dakota, 1986b.

Although three of these tourist sites are located in Custer County which is Pennington County's neighbor to the south, and none are in Lawrence County, travel to and from these sites flows through the three county region, contributing economic benefits. This is especially true for northern Lawrence County since a major transportation artery, Interstate 90, passes through it as do two scenic loops, U.S. Highways 85 and 385; these pass through the historic mining district surrounding the towns of Deadwood, Lead and Central City. In addition, there are several small ski areas in Lawrence County which account for a portion of the tourism activity in the region.

Historically, the primary tourism and recreation season has been during the summer and early fall. While this is still true, there is an increasing emphasis by local chambers of commerce, economic development agencies and tourism-oriented establishments to promote winter recreation opportunities (D. Schenkeir, Deadwood-Lead Area Chamber of Commerce, personal communication, 1986). Downhill and cross-country skiing and snowmobiling opportunities are being promoted with some

success. For example, Figure 18 shows the western portion of the South Dakota Snowmobile Trail Program which represents nearly one-half of all the existing trails in the state (State of South Dakota, 1985). Not shown on the map are the existing downhill ski areas located about 8 kilometers (five miles) southwest of Lead which attract skiers from throughout the region.

Primary Area of Socioeconomic Influence

As portrayed above, Lawrence, Meade, and Pennington Counties are linked by economic ties and geographic location. Therefore, their economies are subject to many of the same influences. However, within the context of potential heap leach gold operations, the majority of impacts are expected to be much more localized. Based on the geographic area of mineralization and present mineral exploitation activities, as well as the residency patterns among persons currently employed at the Homestake and Wharf Resources operations, the primary area of influence for socioeconomic impacts will be the northern portions of Lawrence County, especially the towns of Lead and Deadwood and nearby surrounding environs. The remainder of this section will provide a brief description of key socioeconomic characteristics within the primary area of influence.

Over 60 percent of the population of Lawrence County resides in three incorporated municipalities: Spearfish, Lead, and Deadwood. In addition, approximately 1,100 to 1,200 persons live in the communities of Whitewood and St. Onge, both located in the northern portion of the county. The remaining inhabitants reside in unincorporated areas of the county, principally surrounding the three major towns and in small clusters of homes and farms scattered throughout the county. Most of the farms are located in the northern one-third of the county where the land is more conducive to agriculture, while those homes in the Black Hills area tend to be located in the bottom lands along the major streams in the county. Population data for the three towns for the period 1960 to 1985 is shown in Table 33 along with the rate of change in each over the past fifteen years.

**FIGURE 18
BLACK HILLS SNOWMOBILE TRAIL SYSTEM**

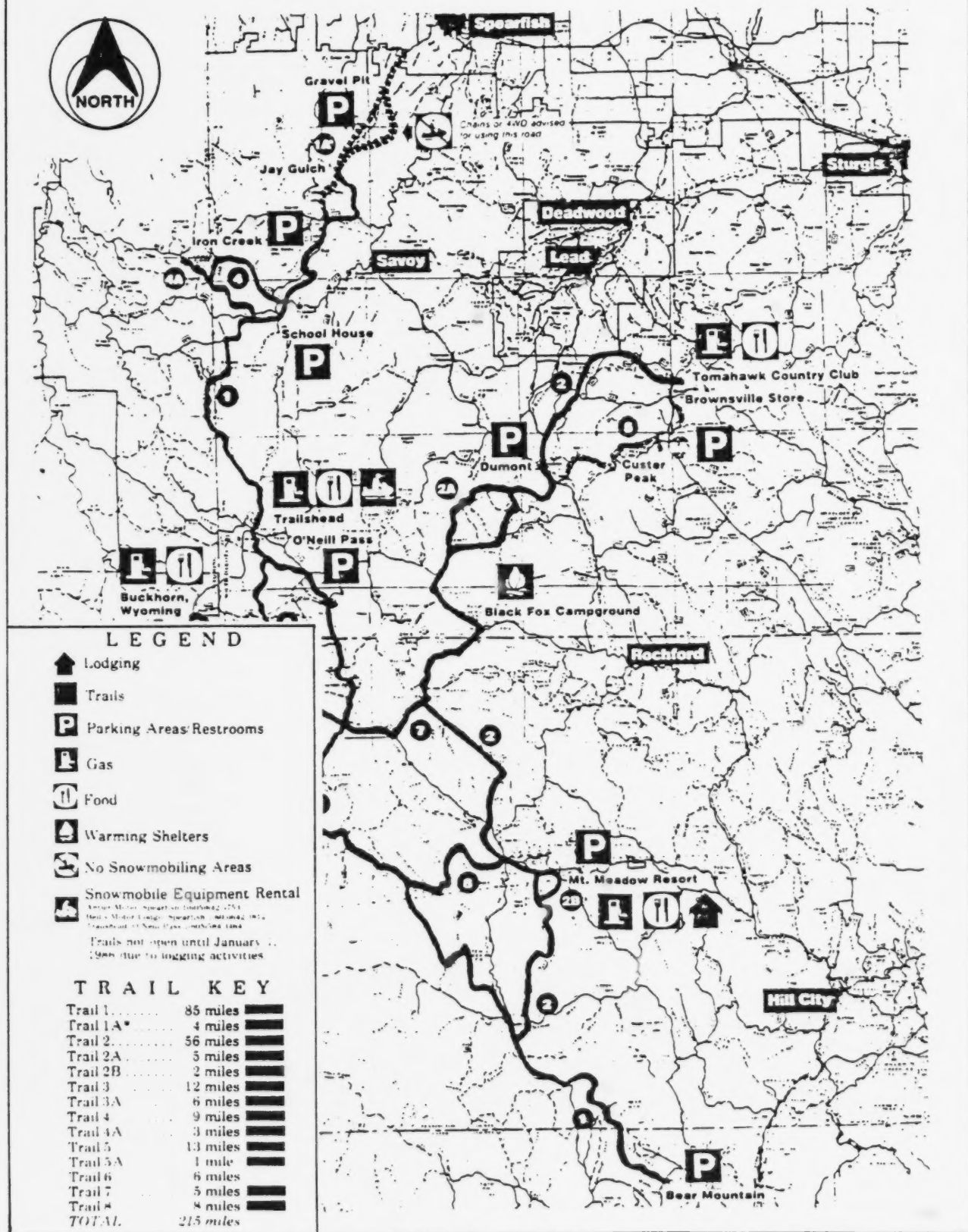


TABLE 33
POPULATION CHANGE, LAWRENCE COUNTY
AND SELECTED TOWNS, 1960 TO 1985

	1960	1970	1980	1985	Annual Percent Change	
					1970-1980	1980-1985
LAWRENCE COUNTY	17,075	17,453	18,339	19,200	0.5	0.1
Spearfish	3,682	4,661	5,251	5,780	1.2	1.9
Lead	6,211	5,420	4,330	4,180	-2.2	-0.7
Deadwood	3,045	2,409	2,035	1,820	-1.7	-2.2

Source: U.S. Bureau of the Census, 1982; Black Hills Council of
Local Governments, 1984.

As indicated above, Lawrence County as a whole experienced slow but steady population growth during the 1970's and the early 1980's. However, the majority of this growth occurred in and around Spearfish. During both the 1970's and the first half of the 1980's, Lead and Deadwood lost population, continuing a trend dating back to before 1960. There are five underlying causes of these shifts in local populations. First, changes have occurred in the location of local employment opportunities. While mining employment has been declining steadily, thereby affecting Lead and Deadwood, employment in other sectors, especially in the manufacturing and services industries concentrated around Spearfish, have been increasing. Second, changes in residential preferences and increased transportation mobility have resulted in an increased tendency for persons employed in Lead and Deadwood to reside elsewhere and commute to work. For example, in the four-year period 1979 to 1983, the proportion of Homestake employees residing in Spearfish increased from seven to 11 percent. A comparable number of Homestake employees reside in nearby Sturgis (Meade County), a town very similar to Spearfish. Both have populations of over 5,000, are located on Interstate 90 offering excellent access to Rapid City, have a higher level of retail trade and personal consumer services available, and are located within 30 to 40 kilometers (20 to 25 miles) driving distance to the mines.

Fourth, the terrain, topography and land ownership have acted as natural constraints to local growth and development. Both Lead and Deadwood are located in areas of steep slopes, limited flat lands and highway transportation corridors established along stream drainages, and surrounded by areas of potentially valuable mineralization deposits. Thus, these communities have been limited in their ability to expand their boundaries or tax bases to respond to changing conditions and the desires for higher levels of public services (C. Koerner, Lawrence County Planner, personal communication, 1986; D. Mueller, Black Hills Council of Local Governments, personal communication, 1986; H. Lux, City of Lead, personal communication, 1986). By contrast, both Spearfish and Sturgis are located in areas of gently rolling hills more conducive to the provision of services and today's tastes in housing. As mentioned above, there is a certain vicious circularity to these trends. Unless something occurs to break the cycle, further population declines might be expected in Lead and Deadwood, with more growth focused on Spearfish and possibly Sturgis.

Finally, Spearfish has been attracting a number of new residents from among the ranks of retired persons. It offers a temperate climate, essential levels of retail trade and services and recreation opportunities, as well as easy access to Rapid City.

Employment and Economic Base

The relative concentration of employment in major economic sectors in Lawrence County has shifted somewhat over the 1980 to 1984 period. The composition of local employment in the county over this period is presented in Table 34.

TABLE 34
COMPOSITION OF EMPLOYMENT IN
LAWRENCE COUNTY, 1980 to 1984

	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>Change 1980-84</u>
Manufacturing	481	477	604	666	710	+229
Mining	1,763	1,776	1,655	1,617	1,631	-132
Retail Trade	1,581	1,635	1,559	1,579	1,590	+ 9
Services	1,698	1,669	1,687	1,781	1,891	+193
State/Local Government	1,214	1,201	1,153	1,159	1,182	- 32
All Others	1,902	1,986	1,938	1,981	1,988	+ 86
TOTAL EMPLOYMENT	8,639	8,744	8,596	8,788	8,992	+353

Source: U.S. Bureau of Economic Analysis, 1986a.

The major shifts have been a decline in total mining employment, offset by increases in the manufacturing and services industries. The former change has been in response to general market conditions for precious and industrial metals, while the latter reflects increased lumber and wood processing and tourism.

These changes have affected each of the three towns differentially with many of the impacts visibly apparent. Recent and ongoing commercial and residential construction are readily evident in Spearfish, compared with little new construction in the other communities. Although there are many hotels, motels and restaurants to serve tourists, there are also many establishments to serve the local population, local commercial business and the agricultural industries. The most recent new construction in Deadwood appears to be a motel, a medical office extension of the hospital and ongoing major highway construction through town to accommodate the heavy volume of tourist traffic. Recently the J.C. Penney retail outlet, the Montgomery Ward mail-order store and an appliance store have closed in Deadwood. Such establishments typically rely on the local residential population to support their operations. The base of such local market-serving establishments continues to decline, being replaced by specialty goods, novelty and

convenience goods stores. Meanwhile, in Lead, the retail and commercial base is virtually nonexistent. There are probably fewer than 20 establishments presently located in Lead. These include one major grocery store; several smaller convenience outlets for gas, liquor and food; several cafes and restaurants; three or four small, older motels; two banks; and a number of miscellaneous stores. In addition, at least three mining companies have offices in Lead, along with several professional offices for dentists, doctors, attorneys, and accountants. However, for a community with a population of over 4,000 inhabitants, this barely even satisfies the essential needs (personal observation, 1986).

The differences are also reflected in local attitudes towards economic development. The Black Hills Council of Local Governments and Northern Hills Community Development, Inc. have targeted Spearfish as a potential development center and are actively pursuing a program of economic diversification. Lead is currently participating in a multifaceted program involving the construction of a shopping center, a motel and small group conference center and new single-family residences. This is being done not so much to achieve new growth, but to stem further declines (H. Lux, City of Lead, personal communication, 1986). Meanwhile, a number of tourist-oriented proposals are being considered in the Deadwood area. These include an integrated western-theme recreation/amusement park, combined with a steam-powered scenic excursion railroad and an operating liquor distillery (D. Schenkein, Deadwood-Lead Area Chamber of Commerce, personal communication, 1986).

Housing

The housing stock within the primary area of influence reflects recent economic trends. According to 1980 census data, more than ten percent of the existing year-round housing stock, or 9.5 percent of the total housing, was vacant (Table 35). A total of 463 seasonal units, or 5.8 percent of the total, were also reported. These were primarily summer cabins located in the limited bottom lands along the larger

creeks and streams in the area. Access to most of these units is provided via Forest Service or county roads, many of which are impassible during the winter.

TABLE 35
SELECTED 1980 HOUSING DATA IN
LAWRENCE COUNTY, DEADWOOD, AND LEAD

	<u>Number of Units</u>	<u>Percent of Total</u>
Lawrence County:		
Total Housing Units	7,955	100.0
Seasonal Units	463	5.8
Year-round Occupied Units	6,738	84.7
Year-round Vacant Units	754	9.5
Lead:		
Total Housing Units	1,876	100.0
Year-round Occupied Units	1,655	88.2 ^{a/}
Year-round Vacant Units	208	11.1
Deadwood:		
Total Housing Units	949	100.0
Year-round Occupied Units	827	87.1 ^{a/}
Year-round Vacant Units	120	12.6

a/ The sum of year-round occupied and vacant do not equal the total housing stock because seasonal units are included in the total.

Source: U.S. Bureau of the Census, 1982.

The reported vacancy rates in Lead and Deadwood were higher than the county average at 11.1 and 12.6 percent, respectively. In addition 30 percent of the occupied housing in Lead and 42 percent of that in Deadwood were renter occupied. Other census data also showed much of the local housing stock to be older structures in fair to poor condition.

According to local officials, this data illustrates one of the more critical problems facing the area, namely, lack of suitable housing. Several factors combine to create the problems. First is the age and general condition of the existing stock in Lead and Deadwood. The homes tend to be small, built in close proximity to each other and

due to the steep terrain, they tend to have small yards, no garages and no room for expansion. The steep terrain also limits the amount of land suitable for development. Thus, since 1980, little new residential construction has occurred in Lead and Deadwood and the local housing conditions, if anything, have deteriorated as the local population has declined. Consequently, more household interest is shifting towards residing in communities such as Spearfish and Sturgis which do not face the same constraints and into unincorporated areas of the county (C. Koerner, Lawrence County Planner, personal communication, 1986; H. Lux, City of Lead, personal communication, 1986).

Another problem is the land ownership patterns surrounding the towns. Most of the land is public and not available for residential development and much of the private lands are potential mining claims in areas of known mineralization where the surface and/or mineral rights owners want to maintain the option of future mining activity.

Finally, the Lawrence County Comprehensive Plan identified a lack of soils suitable for industrial septic systems as a major constraint to residential development in the outlying portions of the county and as a possible contribution to water quality problems. Only 10 to 30 percent of the total area in the Lead-Deadwood vicinity is identified as being suitable for septic system installation. Thus, even if the local employment picture remains stable, the towns' population and tax base may continue to decline (Brady and Chichester, 1969).

As part of the local effort to stem these declines and address the housing problems, several recent initiatives have been undertaken. First, the town of Lead acquired abandoned railroad right-of-way within the town, part of which will be made available for residential construction. Secondly, both Lead and Deadwood have recently annexed property in an area lying on U.S. Highway 35/385 between the two cities. Historically, this land remained unincorporated because of the difficulty in providing water and sanitation service. However, as a result of the formation of the Lead-Deadwood Sanitation District, which

has just completed a major capital improvement program, the area can now be served, providing some opportunity for new development. The district's long-term goal is to extend its service area even farther.

Community Services and Infrastructure

Many components of the local public infrastructure and service delivery systems currently have excess capacity available due to the long-term trend of declining service area populations. In several instances, infrastructure conditions are substandard due to the declining population, tax base and the need to address higher priorities. On the other hand, recent investments and other actions have resulted in modern, up-to-date facilities being available. A brief description of each of the major public systems and services is provided below.

Schools. The consolidated Lead-Deadwood School District No. 40-I is responsible for primary and secondary education in the area. The jurisdiction covers virtually the entire southern half of the county.

The current district was formed in 1972 by the consolidation of the formerly independent Lead and Deadwood school districts. Many residents opposed the consolidation, but it was brought about by economic necessity to maintain efficient operations and a full range of programs in the face of declining enrollments. Even since the consolidation occurred, the district's enrollment has declined by over 1,000 students. The combined current enrollment was 1,396 students during the 1985-86 school year. Enrollments in grades K-6 accounted for 788 of the total, with junior/senior high enrollment of 608 students.

Continuing declines in enrollment and a fire at the Deadwood junior high school building in 1985 have required an ongoing series of adjustments in the use of facilities. Two elementary schools are presently operated by the district, one each in Lead and Deadwood and the high school is in Lead. Following last year's fire, the junior high and high school student bodies were combined in the high school building. The junior high school is in the process of being renovated and modernized. When completed, the structure will house the junior and senior high school and the current high school will be vacated.

According to the district superintendent, the system could accommodate up to 200 additional students without a significant adverse impact. Additional staff would have to be hired and additional capacity put into use. This was not perceived as negative, but rather a positive impact of growth (R. Scheurman, Lead-Deadwood Public Schools, personal communication, 1986).

Law Enforcement. Law enforcement in the area is provided by four agencies: the Lawrence County Sheriff, Lead Police Department, Deadwood Police Department and South Dakota Highway Patrol. The Lawrence County Sheriff's Department, based in Deadwood, is the principal law enforcement agency for the county. The Sheriff's department is housed in a relatively new structure providing offices, communications center, and detention facilities for up to 40 inmates. Some excess office space in the basement is currently used by other county agencies due to the condemnation of the county building. Current staffing includes the Sheriff, five deputies, a bailiff and a paper server. In addition to its own duties, the Sheriff's department provides dispatch services for the Highway Patrol stationed in the area and provides detention capacity for the patrol and local municipalities. According to the Lawrence County Sheriff's Department, current staffing and services are rated as adequate with no critical needs.

The Lead Police Department has six full-time personnel and is housed in the City Hall. The department's jurisdiction includes the incorporated municipal limits. According to the Lead Comprehensive Plan, there is sufficient space in City Hall, although some upgrading of mechanical systems and additional parking spaces are needed. The Lead Police Department is rated as adequate (City of Lead, 1985; H. Lux, City of Lead, personal communication, 1986).

The Deadwood Police Department has five full-time staff, a reduction of one officer in the last year due to budget cuts. The offices are located in Deadwood City Hall, a converted railroad depot, that also houses the fire department and other city offices. The Deadwood Police Chief indicates that the adequacy of local law enforcement is

being maintained but additional staff, updated patrol vehicles and expanded office facilities are all needed (D. Heidzig, Deadwood Police Department, personal communication, 1986).

Two officers of the South Dakota Highway Patrol are based in Deadwood, with other officers stationed in Spearfish and other surrounding communities. The Highway Patrol's major areas of responsibility are law enforcement on Interstate 90 and the various U.S. and state highways in the region according to the Lawrence County Sheriff's Department. No assessment of adequacy is available.

Fire Protection. Municipal fire protection in the area is provided by the Lead and Deadwood Fire Departments. Each of these departments serves not only incorporated limits, but also the surrounding rural areas. Both are primarily volunteer departments, supplemented by several paid full-time professionals. The paid professionals insure prompt emergency response during the daytime when volunteer response can be uncertain. Both departments are housed in their respective City Halls and could benefit from additional space, especially in Deadwood.

The Lead Fire Department is equipped with three major apparatus: a 1986 combination ladder, hose and pumper, a 1972 pumper and a 1979 Mini-Attack quick response pumper. In addition, it maintains several older 4-wheel drive brush/forest fire units. The Deadwood Fire Department is also equipped with three major apparatus: an aerial/ladder truck and two combination pumpers. The ages of these vehicles is not known; however, the Fire Chief indicated that the City and department were saving to acquire a new combination pumper to replace the oldest unit. The Deadwood Fire Department also maintains a smaller 4-wheel drive brush/forest fire unit, is building a similar unit and operates a communications and equipment van.

Since there is no fire protection district established to serve the outlying areas of the county, the Lawrence County Fire Advisory Board assists the established fire departments to develop expanded capacity to deal with the problems of firefighting in rural areas. The primary problem is a lack of water supply. Presently, a 2,500 gallon

capacity tanker truck, owned by the advisory board, is staffed, operated, and maintained by the Deadwood Fire Department. It is available to respond to any fire location in the county. The advisory board is in the process of acquiring another similar unit to serve the Lead-Deadwood area.

Lead has a fire insurance rating of 6 and Deadwood has a rating of 8. Both departments are rated as adequate for current needs and any foreseeable changes (J. Hood, Deadwood Fire Department, personal communication, 1986; T. Mitzel, Lead Fire Department, personal communication, 1986).

Local municipal fire protection is supplemented by other departments in the region under a mutual aid assistance pact. These include departments in the adjoining communities of Spearfish, Sturgis, and the South Dakota Division of Forestry which maintains a forest management and firefighting base outside Lead. For example, when the Deadwood junior high school building burned in 1985, units from all of the above either responded directly or provided coverage in other jurisdictions which had dispatched their units to Deadwood.

Medical Care. Primary medical care in the area is provided by the Northern Hills General Hospital and the Black Hills Medical Center. These two facilities are located adjacent to one another in Deadwood. As is true in other areas of public services, the Northern Hills General Hospital emerged as the surviving entity following the consolidation of two hospitals serving a declining market: one each in Lead and Deadwood. As the local population continued in steady decline during the 1960's and 1970's, the operations and maintenance of two hospitals in a limited population service area became impractical. The existing hospital was selected as a base of operations partially because it was the larger facility and apparently the local physicians supported its choice. The current capacity is 39 beds and it is operating at an average occupancy of 40 percent. The hospital offers a full-range of facilities including emergency room, radiology and surgery (D. Thrall, Northern Hills General Hospital, personal communication, 1986).

The Black Hills Medical Clinic is a recently completed modern clinic, adjoining the hospital. The clinic houses most of the 11 physicians maintaining practices in the Lead-Deadwood area.

Several local officials rated the quality of medical care as satisfactory and were not aware of any critical needs. In the event that specialized care is required, Rapid City, a major regional medical center, is located an hour's drive from Deadwood.

Ambulance service in the Lead-Deadwood area is provided by a private firm in Lead. The service is available 24-hours a day, with staffing done on an on-call basis. The service is funded by fees for services and by an appropriation from Lawrence County. Recently the services operator sought additional funding to upgrade existing capabilities and purchase an additional ambulance.

Solid Wastes. The City of Lead contracts with a private operator for residential solid waste collection and transport within the corporate limits. The City of Deadwood currently provides the service directly, although it is presently considering implementing a system similar to Lead's. Residents are then billed by the cities to recover costs. In both communities, collection and transport for commercial entities is done on an individual contract basis, as is residential service in the outlying rural areas. Individuals in the outlying area also have the option of hauling their solid waste to a landfill site themselves.

There are two sanitary landfills currently serving the area: one in Sturgis, the other in Belle Fourche. Much of the solid waste collected in the area is being transported to the Belle Fourche site because of its available capacity. At the current rate of filling, the site has an estimated 50-year life remaining (K. Peterson, Belle Fourche Sanitary Landfill, personal communication, 1986; H. Lux, City of Lead, personal communication, 1986).

In addition to the sanitary landfills the cities of Lead and Deadwood maintain a dump to the south of Lead off Yellow Creek Road which is open to the public on a fee basis. Materials accepted are

limited to metals and burnables. The cities utilize this site for limited purposes such as disposal of refuse collected in the annual spring trash pickup. The Homestake Mining Company and Black Hills Power and Light also maintain private facilities in this area (H. Lux, City of Lead, personal communication, 1986).

Water and Wastewater. Both Lead and Deadwood rely on the Homestake Mining Company for their water supplies. The municipalities purchase the water from Homestake and bill the respective users, operating the utilities on an enterprise basis. The company owns and maintains the system serving Lead, while the Deadwood system is municipally owned.

Although both systems have areas of older, deteriorating distribution lines and less-than-desired pressure in isolated locations, both report excess delivery capacity available and adequate storage to meet peak daily demands and firefighting requirements. Some transmission line improvements and additional fire hydrant locations were recently completed for the Deadwood system. Overall, these systems are adequate to meet current demand and can accommodate additional growth in demand.

Wastewater treatment is provided locally by the Lead-Deadwood Sanitary District No. 1. The district completed its secondary treatment facility in 1979 to address then existing problems of inadequate treatment. During normal operations the system is operating at its design capacity of 2.3 million gallons per day. The facility also receives a major portion of storm flows from the portions of the communities covered by storm drainage systems. However, at the present time, no major expansions or improvements of the treatment capacity is planned according to the Lead-Deadwood Waste Water District. Some consideration is being given to adding tertiary treatment, but the timing of such improvements is uncertain. The primary influence in determining facility needs is the service area population. Since the formation of the district, little growth has occurred. Furthermore, the district has been unsuccessful in convincing property owners

located adjacent to the district and currently on individual septic systems to join the district. As long as these two situations remain unchanged, there will be little justification for increasing the system's capacity.

Since the formation of the sanitary district, the highest priority need in the area has been the replacement of the flume. The flume is a large wood-construction conduit which carries sewage and storm sewage from most of the community of Lead to the district's primary transmission lines. The flume is over 80 years old and leaks badly. The City of Lead is proceeding with a contract to replace the flume within the next year. Once completed, no major system deficiencies will remain, although the question of the wastewater treatment system's ability to accommodate growth will remain (City of Lead, 1985; H. Lux, City of Lead, personal communication, 1986).

County Roads. Based on the previous experience of the Lawrence County Department of Highways any new heap leach gold mining and processing operation in Lawrence County could be expected to have impacts on the county road system, both during the construction and operational phases of the mine. The level of impact would, of course, depend on the location and nature of the mine operation.

In the past, road problems which have arisen have been dealt with on a case-by-case basis with the mining companies generally participating either by assisting directly in construction and maintenance, by sharing costs, or by providing materials, easements or engineering assistance.

Without specific knowledge of where mining operations might occur it is difficult for highway officials to anticipate what actual needs might arise but it is possible to identify a few key road segments which could potentially be affected by heap leach operations and assess their current status:

- . Gilt Edge Road (Forest Route 170). This is a jointly maintained road with the U.S. Forest Service. It runs from U.S. Highway 385 to Forest Development Road 534 in the vicinity of the Gilt Edge permit area. The county currently maintains the road for 1.1 kilometers (0.7 mile) from U.S. Highway 385. Mining activity in the area would probably require at least regravelling of this segment.
- . Yellow Creek Road. This is a jointly maintained road with the Forest Service and Bureau of Land Management. The public dump facility for Lead and Deadwood and private facilities of the Homestake Mining Company and Black Hills Power and Light are located off this road and, due to its heavy use by various entities, maintenance has been on a shared basis.
- . The Maitland Road was rebuilt about a year ago from Central City to the St. Joe American site. Heavy traffic on this road due to travelers trying to avoid state highway construction east of Deadwood, combined with heavy equipment movement in the area, has elicited complaints from residents about noise and dust.
- . The Terry Gulch road had been planned for reconstruction next year but this is currently on hold awaiting more information on plans in the area by Moruya Gold Mines, Inc.
- . The Trojan Road serving the Wharf Resources Annie Creek mine and a potential route to St. Joe American operations has suffered subsidence problems possibly related to abandoned underground workings and will probably require rebuilding at some point.

The County Road and Bridge Department has typically been in a reactive position with the limited information available about potential mine operations and limited resources of the department allowing little lead time for planning road improvements (C. Williams, Lawrence County Highway Department, personal communication, 1986).

General Government. Most of the key public service delivery systems for the local governments and agencies are discussed separately. However, in the local area of influence there exists one area of concern that transcends the individual services and systems, that being the needs for general administrative and operations facilities.

For many years, the local governments have been experiencing either only modest population growth or actual declines. Their fiscal resources have been comparably impacted. During the same time, inflation has resulted in substantially greater pressure on the expenditures budgets. Consequently, over time the local governments and public agencies have sought ways to become more efficient in their service delivery. The consolidation of the Lead and Deadwood school districts offers a prime example of such adjustments.

While some efficiencies were achieved, the continuing fiscal pressures have resulted in some reductions in service levels. For example, the budget for street maintenance in Deadwood was described as being just adequate for maintenance, but with little allowance for undertaking improvements. Similarly, the Deadwood Police Chief had requested sufficient budget in 1985 to hire an additional officer to increase the department's total staff to seven. Instead, his budget was cut and his staff reduced to a total of five.

The continuing pressures on local government budgets is perhaps no where more apparent than in the administrative facilities. Lead's City Hall is only about 50 percent utilized and is in good structural repair, although substantial mechanical improvements are needed. Deadwood's administrative functions are housed in the old railroad depot which has been converted. The City's fire and police departments are also housed in the same facility. The original County building has been condemned as unsafe, so some county functions have relocated to the basement of the county law enforcement center, while others have temporarily moved to leased space in the downtown retail/commercial district. Both Lawrence County and the City of Deadwood are pursuing

plans to acquire and/or build new administrative facilities, but no firm plans currently exist (C. Koerner, Lawrence County Planner, personal communication 1986; J. Brodsky, City of Deadwood, personal communication, 1986).

Fiscal Resources

Assessed Valuation

Assessed valuation of real property and improvements such as homes and office buildings is a key component of local fiscal resources. It is the basis on which local property taxes are levied by local governments. In the area of influence, property taxes are the primary sources of revenue. Assessed valuation for Lawrence County, the City of Lead, and City of Deadwood is shown for 1984 through 1986 in Table 36 below.

TABLE 36
TOTAL ASSESSED VALUATION IN LAWRENCE COUNTY,
LEAD, AND DEADWOOD, 1984 to 1986

	<u>1984</u> <u>Amount</u>	<u>1985</u> <u>Amount</u>	<u>1986</u> <u>Amount</u>
Lawrence County	\$304,844,984	\$313,043,689	\$334,442,498
City of Lead	72,233,645	71,953,025	73,014,130
City of Deadwood	23,927,799	24,138,004	25,016,350

Note: Assessed valuation as determined by the County Board.

Source: Lawrence County, 1986b.

Lawrence County. In fiscal year 1986, assessed valuation on all vacant and developed land in Lawrence County totalled \$334,442,398. The large majority, or 92 percent of this valuation, derived from non-agricultural property, most of which had improvements in place. Approximately 57 percent of total valuation was from such properties located within city limits, and 35 percent from improved properties

located outside corporate limits. In addition, eight percent of total valuation was derived from properties zoned agricultural, almost all of which are located in unincorporated portions of the county.

Between 1984 and 1986 there have been some changes in the relative shares of assessed valuation in Lawrence County from properties zoned agricultural or non-agricultural and located within or without corporate limits. Most notable has been the increase of nearly four percent in the relative importance of non-agricultural properties outside corporate limits and a corresponding decrease in the share of valuation from similar properties in incorporated locations.

City of Lead. Total 1986 valuation of property in the City of Lead equalled over \$73 million. This accounted for nearly 22 percent of the total county-wide property valuation. The share of county-wide valuation within Lead's corporate boundaries has declined slightly over the last few years, down from almost 24 percent in 1984, corresponding to the countywide decline in the share of valuation from within city limits.

City of Deadwood. As with Lead, the share of total county-wide property valuation located within Deadwood city limits has declined slightly over the 1984 to 1986 period. Total valuation in the city in 1986 was over \$25 million, up from nearly \$24 million in 1984. As a share of the county-wide total however, assessed valuation in Deadwood has declined slightly from 7.8 percent to 7.5 percent.

Revenues

Lawrence County. Because South Dakota counties do not collect sales taxes, property taxes are the main source of revenue. In Lawrence County, property taxes account for approximately 60 percent of the projected 1986 revenue base. Other sources of revenue derive primarily from intergovernmental transfers, as well as from fees for licenses and permits, and interest earnings.

Total taxable property valuation in Lawrence County is derived as a 45 percent share of total assessed valuation. Tax levies for 1985, payable in 1986, were assessed by five entities: school, county, fire

protection, city or township, and sanitation. The total mill levy for the county tax alone was 16.43 mills (\$16.43 per \$1000 of taxable value), of which 13.23 mills is to be used for general county operations. The additional levies were for snow removal, highways and bridges, and the public library.

Between 1984 and 1985, the total county levy was increased substantially, by nearly twelve percent. During the previous year, the county levy had been raised by a much lower margin of under six percent. Approximately one-third of the 1984-85 increase was for highway and bridge reserve; the remainder went to the general county fund.

City of Lead. Current revenues for the City of Lead in 1986 totalled slightly more than \$2 million. Well over half of these revenues, or nearly \$1.3 million, have been applied to the city's general fund. Most of the general fund revenues are derived from taxes, including both property and sales taxes. In 1986, almost \$650,000 accrued to the city in property taxes, accounting for half of the total general fund, and close to \$400,000, or about 31 percent of the total general fund revenues were derived from sales taxes. Over half of this sales tax, however, resulted specifically from back taxes paid by the Homestake Mining Company. Typically, then, Lead's sales tax revenues are considerably lower and account for a somewhat smaller share of total tax collections.

Several other sources comprise the remaining share of the city's general fund. Intergovernmental revenues, primarily personal property replacement tax received from the State, and the county bridge fund transfer provide the most revenue. Other revenues are derived from licenses and permits, charges for goods and services, fines and forfeits, and miscellaneous sources, including lease revenues, interest on investments, and reimbursements. Together, these sources provided an additional \$210,000 to Lead's general fund in 1986.

In addition to its general fund, the City of Lead maintains several other funds under which current revenues are accounted. An amount of \$650,000 was earmarked for capital improvements in 1986;

these revenues were derived primarily from the issuance of bonds and insurance proceeds. In addition, the library fund showed a balance of over \$38,000 that year and the sewer and rehab funds were at \$40,000 and \$5,000, respectively. Revenues for these three funds came primarily from the city or special district mill levies.

City of Deadwood. In 1986, Deadwood's general fund totalled slightly more than \$800,000. Approximately 41 percent, or \$310,000 of these revenues were generated from property taxes and 36 percent from sales taxes. The remaining 23 percent of general fund revenues were derived from a combination of license and other fees, permits, interest, etc. The relative importance of the two taxes and other revenue sources to total general revenues differs notably in Deadwood compared to Lead, where sales tax accounts for a smaller share of general revenues. This difference reflects the difference in the economic base of the two communities, whereby Lead is more heavily focused on mining while Deadwood relies on tourism.

The City of Deadwood applies revenues to a number of funds in addition to the general fund, reaching a total of approximately \$1.4 million in unencumbered funds in 1986. These additional revenue sources include: parking meter; revenue sharing; water project; water enterprise fund; library; sanitation enterprise fund; and Mt. Moriah restoration.

Revenue sources for Deadwood, along with Lead and Lawrence County are indicated in Table 37.

TABLE 37
REVENUE SOURCES FOR LAWRENCE COUNTY,
LEAD, AND DEADWOOD, 1986

<u>Revenues Category</u>	<u>Lawrence County</u>	<u>Lead</u>	<u>Deadwood</u>
Total	\$5,498,190	\$2,015,750	\$1,704,444
	<u>Percent of Total</u>		
General Fund	64.2	63.6	47.3
Property Tax	37.0	31.2	29.1
Sales Tax	--	19.8	18.2
Inter-Governmental Permits	2.2	5.7	--
Licenses, Service Charges, Fines	--	2.3	--
Other	25.0	4.6	--
Revenue Sharing	--	--	2.3
Library	2.8	1.8	2.3
Other	33.0	26.6	48.1

Source: Lawrence County 1986a; City of Lead, 1986; City of
Deadwood, 1986.

Expenditures

The pattern of appropriations of general funds by the county and the cities of Lead and Deadwood are shown in Table 38.

TABLE 38
BUDGET APPROPRIATIONS FOR LAWRENCE COUNTY
LEAD, AND DEADWOOD, 1986

<u>Expenditure Category</u>	<u>Lawrence County</u>	<u>Lead</u>	<u>Deadwood</u>
Total	\$5,498,190	\$1,282,607	\$1,704,444
Percent of the Total			
General Government	25.2	22.0	6.0
Public Safety	14.8	23.8	14.3
Public Works	25.2	49.7	50.2 ^{a/}
Health	5.3	1.5	--
Culture and Recreation	--	3.0	13.4
Other	29.5	--	16.1

a/ Appears as "Highways and Streets" in Deadwood Budget.

Sources: Lawrence County, 1986a; City of Lead, 1986; City of Deadwood, 1986.

Lawrence County. As shown in Table 38, the county's budget appropriations for 1986 totalled nearly \$5.5 million. General government and public works account for the highest appropriations among the itemized categories. Nearly 30 percent of total appropriations are in the "other" category, however. These funds are primarily for planned capital outlays, including possible restoration of the historic opera-house which suffered severe fire damage, and participation in infrastructure improvement costs to support a new residential and commercial subdivision.

The 1986 budget appropriations by the county mark an increase of about 36 percent from the previous fiscal year; total expenditures increased between 1984 and 1985, as well, but by a smaller margin of slightly more than 10 percent. Over this period, the share of funds appropriated for general government and public works decreased as the share earmarked for capital outlays increased tremendously.

City of Lead. In Lead, the greatest share of funds appropriated to any single budget item went to public works, totalling nearly half of the general fund total appropriations in 1986. Over one-third of the public works budget is for streets, including some minor capital improvements and general maintenance. An additional large public works expenditure goes for solid waste pickup and disposal, which is provided on a contract basis by a private firm.

Public safety also received a large share of general revenue funds in Lead for fiscal year 1986 that was greater than in either the county or neighboring Deadwood. The share of appropriations going to general government in Lead accounted for much of the remaining funds; at 22 percent of the total fund, Lead's relative appropriation for general government was close to the county's.

In addition to the general fund appropriations, revenues for the city's other funds were apportioned fully. Most of the \$650,000 for capital improvements was earmarked for construction of a proposed recreation center and \$150,000 of the total will go to fund a development corporation which will be involved with actual residential development and provide assistance on commercial and motel development.

City of Deadwood. As in Lead, public works received the largest share of Deadwood's total budget, accounting for half of all general funds. General government is funded at a much lower level in Deadwood than in either Lead or the county. However, culture and recreation accounts for a much greater share of Deadwood's budget. The "other" category, receiving about 16 percent of Deadwood's general funds, includes in this case enterprise funds such as water and sanitation, and debt service.

Recreation Resources

In addition to mining, tourism and outdoor recreation play key roles in the local economic base and in the lifestyles of local residents. The Black Hills abound with a variety of public and private

recreation opportunities. The majority of these opportunities are supported by the public lands of the Black Hills National Forest administered by the U.S. Forest Service.

In the immediate Lead/Deadwood area, the primary developed recreation sites are the Deer Mountain and Terry Peak ski areas. The two ski areas are located on adjacent peaks about 5 kilometers (3 miles) southwest of Lead and are the only downhill ski areas within a 150-mile radius of Lead/Deadwood. The existing Wharf Resources Annie Creek and Foley Ridge projects are located 1.5 to 2.5 kilometers (1 to 1.5 miles) west and northwest of Terry Peak and major areas of exploration surround both areas on three sides. Some leased public land is involved in the Terry Peak operation, while the majority of the property and all of the Deer Mountain ski area is in private ownership.

Typically each of the ski areas sells between 40,000 and 60,000 lift tickets in a season, serving a regional market. Approximately 50 percent of the total skiers are local residents, with the remaining visitors coming from the rest of South Dakota, Wyoming, Montana, and North Dakota (J. Mattson, Deer Mountain Ski Area, personal communication, 1986; G. Akrop, Terry Peak Ski Area, personal communication, 1986).

The sole remaining public developed recreation site in the immediate vicinity is the Hanna Campground, located on Spearfish Creek, about 3 kilometers (2 miles) off of U.S. Highway 85 south of Cheyenne Crossing. Access is via Forest Service Road 222.

Numerous other Forest Service developed recreation sites exist in the forest, but are more distant from Lead-Deadwood. Two campgrounds are located on Schoolhouse Gulch, off of Spearfish Creek, about 16 to 18 miles from Lead via U.S. Highway 85 and U.S. Highway 14 ALT; three large lake and reservoir-based recreation areas are located in Pennington County 40 to 48 kilometers (25 to 30 miles) south of Lead-Deadwood; and several developed campgrounds and picnic areas are located around the community of Nemo in the southeast corner of the county (U.S. Forest Service, 1980; 1986b).

A substantial amount of dispersed recreation is also supported by the public lands. Deer and game bird hunting, fishing, hiking, camping and four-wheel driving are all popular activities. According to local officials, all of the areas where recent gold exploration is occurring and where potential operations could be located are excellent hunting areas. Spearfish Creek, rated a blue ribbon trout stream in some areas, offers the best fishing, with fishing quality characterized as good on Whitewood, Deadwood, Whitetail and Strawberry creeks following a recent cleanup effort by the Homestake Mining Company. Fishing quality on other streams varies from fair to poor depending on the volume of flows and water quality. Stocking programs are relied on to maintain fish populations in all of the streams (C. Webster, Lawrence County Conservation Officer, 1986). Two elk habitat areas exist in the region--one each located southeast and southwest of the Lead/Deadwood area. Because of limited herd sizes and harvesting quotas, only a few hunting licenses are issued each year. Demand for the licenses is heavy, so licenses are issued using a lottery. No licenses are currently issued for hunting elk in the habitat area encompassing the Two Bit Creek study area (D. Linde, South Dakota Department of Game, Fish, and Parks, personal communication, 1986).

As mentioned previously, the region is becoming increasingly well known for its snowmobiling opportunities. Nearly one-fourth of the state's developed snowmobile trail system exists in Lawrence County and one-half of the total system exists in the Black Hills (see Figure 18). An annual event in the area which brings snowmobile manufacturers and magazine publishers together to test the new products is attributed with spurring an increase in snowmobiling interest in the area. Most of the trail system is located to the west and south of the general area of mining interest.

Snowmobiling and cross-country skiing on a more dispersed and unorganized basis occurs throughout the area on the many logging roads developed to support the local timber industry (P. Mock, Black Hills National Forest, personal communication, 1986).

Lifestyles and Attitudes

A common link among most residents and visitors to the local area of influence is the area's natural resource base. Whether involved in mining or timber harvesting, a permanent resident, an owner of a vacation home in the region, or a tourist, it is the geological, biological, and scenic resources which are primarily responsible for human presence in the region.

With respect to the current level and pattern of development, gold mining is the key influence. The first publicized discovery of gold in the area occurred in 1874 and the Homestake Mining Company became a primary economic force in 1876. For the past 110 years, the Homestake Mining Company and its operations have not only been a stabilizing force, but also the predominant economic force driving the region's entire economic structure. The mine created employment opportunities which attracted new workers and households to the area. The residents in turn generated demands for food, housing and other household commodities. Initially, these items were transported into the region because they were not available locally. Over time, these needs spawned the local agriculture and service and trade base. The mining activity itself, along with the indirect household needs provided a catalyst for the local timber industry to become established and supported the development of the railroad into the area. At the same time, the company found itself in the position of assuming many of the functions of a local government and non-mining private enterprise in the development of a residential community, retail base and public infrastructure.

This historical relationship has carried over to present times. According to several local officials, it is the perspective of many residents that mining continues to be the economic mainstay in the local economy. Tourism, timbering/wood-processing, recreation and manufacturing are beneficial and help in achieving a semblance of diversification, especially in other areas of the county, but mining is the dominant activity.

Furthermore, for years the Homestake Mining Company has been perceived as a benevolent, paternal entity, which provided secure employment and demonstrated real concern for its employees, families and their communities. In return, it expected and fostered a deep sense of loyalty. Thus, when faced with the prospects of additional mining, there is a strong sense of positive and beneficial impacts, that is, a source of economic livelihood. This may be especially true since the level of employment at Homestake has been declining consistently over the past four to five years.

Against this all-pervasive background, there are several other perspectives and lifestyles that must be considered. One is that of the temporary residents, that is, summer homeowners in the area and the many vacationers to the region. These persons are attracted by the area's scenic beauty, recreational opportunities and its historic and current links to mining. Although mining, the development of transportation and community infrastructure, and in many instances, even the land in private ownership on which the summer homes are built, are to some extent responsible for their attraction to the area, their perspective is focused on leisure pursuits, not economic livelihood. They are therefore, typically opposed to actions which might directly or indirectly adversely impact their enjoyment of the area. Such impacts could include additional noise or traffic in the vicinity of residences, possible loss of the dwelling itself in instances where the structure is built on leased land or on land where another party owns the mineral rights, or degradation of visual and aesthetic resources resulting from the operation's activities. The latter issue seems to be related primarily to the fact that the heap leach process is primarily surface-oriented compared with the underground operations more commonly associated with mining. Obviously the Homestake open cut operation in Lead is not underground, but neither does it seem to evoke the same opposition from the temporary residents. This dichotomy of economic livelihood versus leisure pursuits defines one of the primary sources of potential lifestyle conflicts associated with mining.

Somewhat closely aligned with the summer homeowners and tourists in their opposition to mining, but for different reasons, are interest groups representing recreation and environmental concerns. The general perspective of these interest groups is that extractive industries such as mining result in degradation of the environment, interfere with other, non-consumptive and non-extractive uses in the area and should, therefore, be restricted or prohibited. Although these interests are recognized among local residents, no organized group or individual was identified during numerous conversations with local officials as being especially critical or active in their opposition to further heap leach mining. Representatives of both the mining industry and local government tend to share the perspective that while the existing natural environment and other non-mining uses of the environment are important, mining and other uses can coexist, and mining can and should occur.

The Lawrence County Zoning and Subdivision Regulations (Lawrence County, 1986c) allows for mining and related activities within all zone districts as a use by right. The zoning ordinance requires a special use permit for purposes of insuring that adjacent land uses are properly buffered and protected, and to insure proper reclamation of the site when mining ceases.

The goals and policies statement of the Comprehensive Plan (Brady and Chichester, 1969) further reinforces these two points. The extractive industry policies are:

- . In order to insure continued development of natural resources prior to development of the land for other purposes, extractive industries should be allowed to locate in areas known to have deposits of minerals and materials.
- . After the industry has depleted the raw material, or has been abandoned, the land should be reconditioned in such a fashion that it can be used by some other type of land use.

However, in an effort to address possible conflicts, the county uses a conditional use permit system, not to deny mining companies the right to extract minerals, but to reasonably condition the operation, when deemed necessary, for the protection of public health, safety and welfare.

Another common perception regarding heap leach mining identified during discussions with local officials and residents, was that much of the earlier and to some extent the continuing consensus was based on a combination of uncertainty, ignorance and fear along with several events/actions of some of the mining operations.

Several comments were received indicating that, on the one hand, opposition was raised because residents just were not sure of the location, extent and timing of exploration or proposed operations. On the other hand, the lack of this information effectively limited the voicing of specific concerns, for example, the potential for adverse impacts on either of the developed downhill ski areas. The managers of these facilities were concerned about the potential for impacts, but could not elaborate specifically because they did not have sufficient information regarding these operations.

Ignorance and fear were also cited as factors underlying the expressed concerns, especially with regard to the cyanide mineral removal process and the design and operation of the heap leach facility itself. Although the use of cyanide solutions is well-established and apparently is also used by Homestake in its processing, it is unfamiliar to most individuals. Furthermore, there has been an overall heightened awareness of hazardous materials and environmental concerns in recent years. When faced with the prospect of an industrial operation using the process, concerns and opposition were voiced.

Finally, the actions of several mining companies contributed to some sense of mistrust and concern. First, the mining companies tend to be less than open with respect to their exploration activities and plans for operations. This behavior is frequently necessary to protect corporate interests. Secondly, several mining companies were faulted

for their dealings with local residents and property owners. For example, one company exercised its rights to vacate current residents from its property with 30-to-50 day notice under the terms of a lease agreement between the parties. While the company was within its rights to do so, the manner in which it was done and the fact that the company was not in the position of imminently undertaking operations, irritated and angered some residents; it had not been done with the same sensitivity, forethought and concern as Homestake would have used. Finally, there were a few "incidents" in the initial phasing of the Wharf Resources Annie Creek operation. Apparently, one of these involved an overflow of the primary containment pond following a heavy early spring blizzard. None of the individuals contacted cited any adverse impacts of the accident, but it nevertheless fostered mistrust and concern.

By almost unanimous consent, an increased level of understanding and awareness regarding the process and heap leach operations, as well as efforts by several mining companies to improve their operations and work within the community have diminished the level of concern and conflict. However, the uncertainties stemming from a lack of specific information regarding anticipated development and community sensitivity to the manner in which mining affairs are handled continues (C. Koerner, Lawrence County Planner, personal communication, 1986; H. Lux, City of Lead, personal communication, 1986; J. Todd, Trojan area resident, personal communication, 1986; H. Scholz, Wharf Resources Ltd., personal communication, 1986).

A positive step to address at least some of the residual concerns is currently underway at the local level. The Lawrence County Task Force on Mining has been established. Comprised of members of local government, civic organizations, the mining industry and property owners, the Task Force is considering ways to minimize further conflicts. The primary results of the Task Force are expected to be the requirement that a comprehensive socioeconomic impact statement be prepared and approved prior to the issuance of a conditional use permit for an extractive industry and the establishment of a buffer zone surrounding areas of active operations separating the operations from

adjoining land uses. When finalized, these stipulations will be incorporated into the Lawrence County Zoning and Subdivision Regulations.

Descriptions of Alternative Mining Sites

Active exploration and feasibility assessments for numerous gold heap leach facilities are currently occurring with respect to locations to the west, southwest and east of the Lead-Deadwood area. Although the general socioeconomic environment is the same for each of these areas there are some variations in site-specific characteristics. A brief discussion of each of these areas is provided below.

Raspberry Gulch

The Raspberry Gulch site is located approximately 8 kilometers (5 miles) southwest of Lead. The area is located north of the confluence of the east and west forks of Spearfish Creek. Land in the immediate and surrounding areas is predominately under Federal government ownership and is managed by the U.S. Forest Service.

Several areas of permanent and seasonal occupancy residential development exist in the vicinity of Raspberry Gulch. Dutch Flats is located just north of the site. It contains more than 20 homes and an estimated 50 additional lots. Several clusters of homes, mostly for seasonal occupancy, are located near Cheyenne Crossing and along Spearfish Creek, just to the southwest of the site. Finally, two subdivisions of permanent and seasonal homes are located approximately 2.4 kilometers (1.5 miles) east-southeast of the site along U.S. Highway 85.

Recreation occurring in the vicinity of Raspberry Gulch includes the region's only two downhill ski areas. Dispersed recreation in the area includes cross-country skiing, hunting and fishing. Spearfish Creek is rated as the best stream fishing in the region.

Yellow Creek

The Yellow Creek site is located due south of Lead in the Yellow Creek drainage. Land ownership is a combination of private and Federal

government with the public lands under the management of the Bureau of Land Management. Adjoining land uses in the general vicinity include limited residential development and several public and private dump sites. Therefore, the area already receives heavy truck traffic. Some additional residential development exists about 1.6 to 2.4 kilometers (1 to 1.5 miles) to the east and west of the site along U.S. Highway 85 and U.S. Highway 385. A ridge line separates these areas from direct visual contact with the site. According to local sources, only limited dispersed recreation occurs in the area.

Two Bit Creek

Located approximately three miles east of Lead-Deadwood, the Two Bit Creek site involves an area of private and federal government lands. The Federal lands are administered by the U.S. Forest Service. Access to the area is provided by U.S. Highway 14 ALT east from Deadwood, then south on a Lawrence County road along the Peedee Gulch and finally via a U.S. Forest Service road. Several clusters of permanent and seasonal residential home developments exist along the Lawrence County road, some within a mile of the mining area. As in Yellow Creek only limited dispersed recreation occurs in the area, primarily hiking, hunting and 4-wheel driving.

CHAPTER 4

POTENTIAL IMPACTS AND CONCERNS

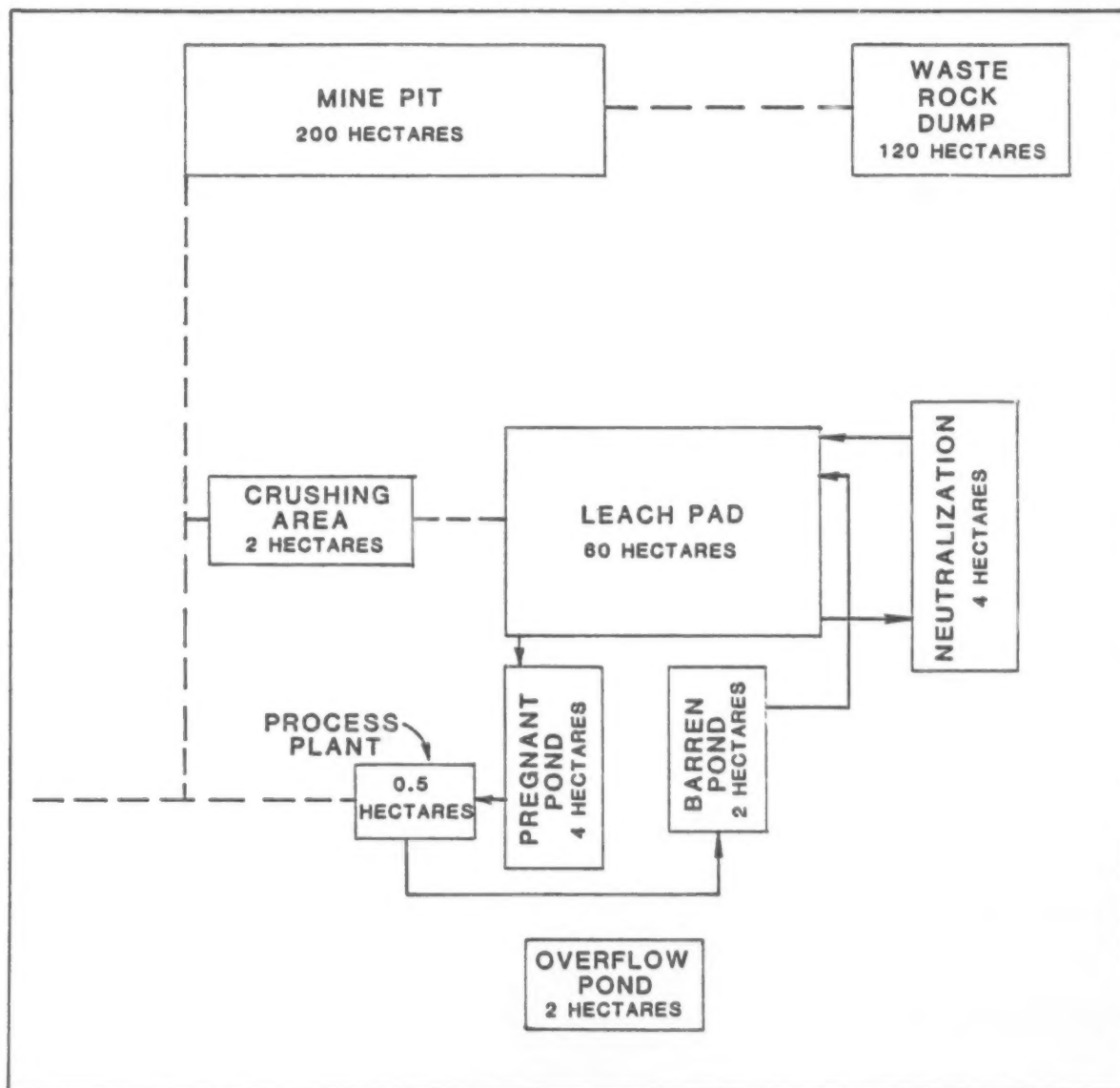
HYPOTHETICAL CYANIDE HEAP LEACH FACILITY

The cyanide heap leach facility described below is a hypothetical mining operation that is a composite of several operating mines. It is not intended to portray a specific existing mine. The facility is shown in a schematic diagram in Figure 19. Each of the components is discussed in more detail in later sections. The entire hypothetical heap leach facility disturbs approximately 400 hectares (1,000 acres) and employs about 100 people throughout its 10-year life.

To assess potential impacts, this hypothetical facility is imposed onto three actual locations in the northern Black Hills (refer to Figure 2). One site is located 8 kilometers (5 miles) southwest of Lead in the Spearfish Creek drainage near Dutch Flats, along Raspberry Gulch. The second site is located 3 kilometers (2 miles) southeast of Lead in the Whitewood Creek drainage along Yellow Creek. The third site is located near Dome Mountain and Two Bit Creek about 5 kilometers (3 miles) east of Deadwood in the Bear Butte Creek drainage. All three sites are near ore bodies in the headwaters of their respective drainages.

It is assumed that the hypothetical mine is in compliance with all requirements of the State of South Dakota and that all necessary permits have been obtained. It is further assumed that a monitoring program was set up and site-specific baseline data were collected in conjunction with the permitting requirements for the hypothetical mine. Water consumption is minimal since the process recycles the working solution. The small amount of water needed for process makeup (loss of 5 to 10 percent from evaporation) and domestic consumption is obtained from wells. The cyanide process is a closed system and will not discharge fluids to surface or ground waters during normal operating procedures.

FIGURE 19
SCHEMATIC DIAGRAM OF THE HYPOTHETICAL
MODEL HEAP LEACH FACILITY



--- ROADS
 — PIPELINES

The mine is described below in sufficient detail to enable an assessment of potential impacts. However, it has not been designed for specific topographical variations or variations in ore bodies which may be encountered at the three different sites. Although this mine design is typical of mines that might be placed in the area, and facilitates the discussion of impacts, other designs may be more appropriate in actual circumstances.

Mine Pit Area

Ore is removed by the open pit method. Prior to excavation, vegetation is removed and the topsoil stockpiled. Daily blasting with 0.3 kilograms of ANFO per metric ton (0.5 pounds of ANFO per short ton) of broken rock in 8-centimeter (3-inch) drill holes loosens the rock. The material is then removed from the pit by hydraulic shovels, rubber-tired front-end loaders, and 35-metric-ton (40-short-ton) capacity trucks. Pit construction consists of 6- to 7.5-meter (20- to 25-foot) benches and a 45-degree pit wall. The pit will not be at a depth that would intercept ground water. Surface runoff resulting from precipitation is collected by maintaining inward-sloping benches. Collection sumps on these benches hold excess water for use in sprinkling roads and dumps for dust control. Sedimentation from exposed mine areas and the waste dump fill is largely controlled by temporary sediment collection ponds. Diversion ditches were constructed to divert runoff around the mine pit and back into the natural drainages downstream from the disturbed area.

During reclamation, benches will be revegetated. The pit will not be backfilled because a change in metal prices or technology may make the processing of remaining ore economically viable.

Approximately 13,500 metric tons (15,000 short tons) of waste rock and ore are mined daily. Of this, 4,500 metric tons (5,000 short tons) are ore and 9,000 metric tons (10,000 short tons) are waste rock. The mine pit will disturb about 200 hectares (500 acres).

Waste Rock Disposal Area

Waste rock from the mine pit is hauled by 35-metric-ton (40-short-ton) capacity haul trucks to a nearby disposal area which was prepared by removing vegetation and stockpiling the topsoil. The waste disposal site will cover approximately 120 hectares (300 acres) and be about 15 meters (50 feet) high. During reclamation, the mine dump will be graded, topsoiled, and revegetated.

Roads

Roads in the facility are single-lane, 9-meter-wide (30-foot-wide) dirt roads. Water is directed to drainage ditches and culverts. Settling sumps are provided where necessary to settle suspended solids. Cut and fill slopes will be revegetated as needed early in the project. Where possible, roads are located away from streams to provide adequate buffer areas. Dust is controlled by watering or surfacing with treated process waste or waste rock. Reclamation of abandoned haul roads and access roads will involve ripping hard surfaces as necessary, recontouring, topsoiling, and reseeding.

Crushing Facility

Ore is hauled by truck to the crushing facility where it is stockpiled. It is later transferred to a primary crusher by a dozer. The crushed ore is transferred to a secondary crusher where it is ground to less than 3.18 centimeters (1.25 inches). The crushed ore is stockpiled for subsequent hauling to the leach area. The pieces of crushing equipment, which include a vibrating grizzly jaw crusher, a cone crusher, rolls, and vibrating screens, are portable, trailer-mounted units. For pH control in the leaching process, 0.75 to 1.0 kilograms of lime per metric ton of ore (1.5 to 2.0 pounds of lime per short ton) are added in the crushing circuit. The crushed ore is transported in trucks to the leaching pad. Dust suppression is accomplished by the use of water spray and/or dust collection devices. Approximately 2 hectares (5 acres) are disturbed by this facility. They will be topsoiled and revegetated during reclamation.

Heap Leach and Process Area

The heap leach and process area consist of a one-time-use heap pad system, pregnant pond, barren pond, neutralization pond, overflow/fresh water pond, and recovery plant as shown in the schematic drawing, Figure 19. The total disturbed acreage will be 80 hectares (200 acres). Of this, the heap leach area will comprise 60 hectares (150 acres) and the process area will comprise 20 hectares (50 acres). The heap leach operation will be a closed system with no discharge to surface or ground waters. Water balance of the heap and ponds have been designed to meet the State of South Dakota requirements for probable maximum precipitation (PMP). In the study area the PMP is 82.6 millimeters (3.25 inches) in 1 hour and 480 millimeters (19 inches) in 6 hours. The components of the heap leach and process area are described in more detail below. The design detail for the pad liner and pond linings is generally that preferred by the State of South Dakota. Other designs may be equally suitable.

Heap Leach Facilities

The leach heap area contains the pad and leak detection system, ore heaps, sprinkler system, heap drainage collection system, and stream diversion ditches. The soil below the heap has been tested and found suitable for heap stability. Before pad construction was initiated, vegetation was cleared from the site. The topsoil was removed and hauled to the topsoil stockpile. The pad base was graded and sloped to permit containment as well as drainage of the leached solution to the appropriate collection areas. Natural drainage was diverted away from the heap and pond area into a diversion ditch. The heap pad system consists of 20 centimeters (8 inches) of clay covered by 30-mil PVC, which is in turn covered by geotextile fabric. A French drain system has been constructed beneath the clay to provide leak detection. This leak detection system drains into the pregnant pond.

After the ore is crushed, it is loaded into haul trucks and end dumped as lifts on the pad. A front-end loader spreads the ore into 3- to 4.5-meter high (10- to 15-foot-high) lifts. Each lift is ripped by a dozer to improve infiltration for the leach solution. Subsequent lifts are added and leached. The height of the ore heaps is from 6 to 12 meters (20 to 40 feet).

The four ponds are located near the ore heap pad as shown in Figure 19. The soil beneath the ponds has been tested and found suitable for stability of the ponds. Construction of the ponds occurred after vegetation had been removed and topsoil had been hauled to the topsoil stockpile. The pond liner consists of 30 centimeters (12 inches) of clay, 30-mil PVC, 30 centimeters (12 inches) of sand, geotextile fabric, and 30-mil hypalon. The leak detection system consists of the sand layer which drains into a channel. A standpipe is connected to the channel so that samples may be taken.

The recovery plant contains the facilities to remove the gold and silver from the pregnant solution. The soil has been tested and found to be adequate for foundation stability. Vegetation and topsoil were removed from the foundation area and the topsoil stockpiled. The building contains carbon columns, a stripping solution tank, and a secured area for the production of dore (gold and silver bars).

A 2.4-meter-high (8-foot-high) mesh wire fence encloses the entire area containing the heap, ponds, and recovery plant. Signs are posted along the fence warning that cyanide is in use and that no trespassing is allowed. Strips of flagging are strung above the barren and pregnant ponds to deter birds from landing in the ponds. The lined collection ditch downgradient from the heap is partially filled with coarse rock to prevent birds from using the ditch.

Leaching Process

The cyanide solution for the leaching process is made by first adding caustic soda (sodium hydroxide) and then adding sodium cyanide. Free and total cyanide concentrations are approximately 225 mg/l and 250 mg/l, respectively. The pH is 10.5. The cyanide solution is

pumped from the barren pond to the top of the heap through PVC pipe. The pipes are arranged so that accidental leakage can be readily collected and contained. A sprinkler system is placed on the heap in a 6- by 12-meter (20- by 40-foot) grid pattern to provide overlapping coverage of the surface. The cyanide solution is sprayed through wobbler-type sprinklers at a rate of 12 liters per square meter per hour (0.3 gallons per square foot per hour). The cyanide solution leaches the precious metals from the ore and collects in a ditch located downgradient from the heap, which drains by gravity to the pregnant pond.

The pregnant solution is pumped to the recovery plant where gold and silver are extracted. The concentration of metals in the pregnant solution are approximately 30 mg/l iron, 5 mg/l arsenic, 1 mg/l cobalt, 1 mg/l gold, and 0.005 mg/l silver. The pregnant solution is fed through a series of columns containing granular activated carbon. As the solution flows through the carbon, gold and silver are adsorbed onto the carbon surface. When the carbon is loaded to capacity with metals, it is removed and stripped in the pressure strip tank with an alcohol caustic cyanide solution. The gold and silver is then removed from the stripping solution by electrowinning. The stripped carbon is regenerated by heating in a kiln and washing with nitric acid.

Cyanide at a rate of 0.3 kilograms per metric ton (0.5 pounds per short ton) of solution must be added to the barren solution at the outflow of the recovery plant. Adjustments to the pH of the process solution can also be made before the process circuit is repeated.

Closure Plan

Closure will consist of the neutralization of the spent ore heap, disposal of the process solution and neutralization solution, and decommissioning and reclamation of all facilities. The neutralization process consists of rinsing the spent ore with a hypochlorite solution until the spent rinse solution contains less than 0.75 mg/l of total cyanide. This method, the alkaline chlorination process, will be used

to oxidize free cyanide and cyanide from weakly bonded cyanide complexes. The hypochlorite solution will contain chlorine at a concentration of approximately 1,000 mg/l free chlorine and have a pH between 10 and 11. The solution will be sprayed on the heap using the same sprinkler system used for the leaching operation. The rinsing solution will collect downgradient from the heap and will be pumped to the neutralization pond, where it will be recycled through the heap. The spent rinse solution from neutralization and the process solution will be disposed by evaporation in the ponds. Any residue remaining from evaporation will be tested for metals and cyanide and disposed of properly.

After the neutralization is complete, the facilities will be dismantled, sold as scrap, or buried onsite. Equipment which may contain cyanide or other hazardous materials will be thoroughly cleaned prior to removal from the project site. After the recovery plant is decommissioned, the concrete foundation will be broken up and buried. The linings from the ponds will be dug up and buried. The pond area and recovery plant area will be restored to their natural contours. Topsoil from the stockpile will be applied and the area will be reseeded.

The neutralized heap pile slopes will be contoured to the ground surface. The pad liner will be punctured to allow natural drainage. Topsoil will be spread over the pile and the area will be reseeded.

ACCIDENTAL RELEASE OF CYANIDE SOLUTION

A properly designed and operated cyanide leaching project would not be a greater threat to environmental quality than any other industrial development of a similar scale not involving the use of cyanide since cyanide solutions are not discharged under normal operations. However, for purposes of evaluating impacts, two types of accidental releases of cyanide process solution, which would be highly unlikely at a well designed and operated mining operation, will be analyzed for potential effects. The two types of accidental releases include:

- . Overflow of the pregnant solution pond; and

- . Release of cyanide solution from a leak in the pregnant pond liner.

The discussion will evaluate factors in the environment which would attenuate cyanide and metals toxicity, determine approximate concentrations of toxic substances at selected points of contact, and define impacts of the spill on natural resources. This analysis is not concerned with the likelihood of an accidental release or the exact mechanics of a pond overflow, leak, or backup system failure.

Several chemical and biological processes, as shown in Figure 20, have the potential to attenuate cyanide when it is released to the environment. These processes which are discussed in detail in Appendix B, result either in degrading or transforming free cyanide into a less toxic species.

Pond Overflow

The overflow of the pregnant pond has occurred during the spring-time due to a combination of snowmelt and a heavy thunderstorm. The concentration of cyanide in the pregnant pond has been reduced by dilution to 200 mg/l free cyanide and 225 mg/l total cyanide. The concentrations of metals are approximately 25 mg/l iron, 4 mg/l arsenic, 1 mg/l cobalt, 1 mg/l gold, and 0.004 mg/l silver. Actual spills at cyanide heap leach operations have ranged from very small to 23,000 cubic meters (6 million gallons) (refer to Appendix D). For this case, 100 cubic meters (27,000 gallons) were released from the pond at a rate of 2.8 liters per second (45 gallons per minute) over a 10-hour period. After flowing across the saturated ground which is partially snow covered for approximately 0.8 kilometer (0.5 mile), the spill enters surface water.

The effect of a pregnant pond overflow on surface water depends on the amount of dilution and attenuation. These are functions of the overland distance traveled, the distance to a major drainage, and the flow in the drainage. The attenuation of cyanide in this example spill is based on an actual spill where cyanide solution with 200 mg/l

cyanide flowed across soil for approximately 0.8 kilometer (0.5 mile). The spill occurred in the spring when temperatures were cold and the ground was partially frozen. The attenuation for free cyanide was a two order magnitude decrease (Appendix D). Because data on attenuation of cyanide in streams are not available, dilution will be the only factor considered in this analysis for reducing the concentration of cyanide once it enters the stream. This approach is very conservative and does not recognize that chemical and biological processes will continue to attenuate cyanide (Figure 20).

In the pond overflow example, the release occurs during a period of heavy precipitation, and snowmelt runoff. The drainages under the conditions are at annual peak flows. Therefore, considerable dilution of the cyanide and heavy metals in the pregnant pond solution occurs. The impacts of the spilled cyanide and metals on the environment are assessed by comparing the resulting concentration of these substances in the environment with EPA toxicity criteria for aquatic life, which are the most stringent criteria in use.

Pond Leak

In the second example, the release of cyanide solution from the pregnant pond occurs through a small leak in the pond liner and leak detection system. The leak from the pond goes unnoticed until cyanide is detected in the ground water at the monitoring well downgradient from the process area. Little is known about the leak, including when it started, the rate of leakage, or the total volume of pregnant pond solution that has leaked from the pond. The concentrations of free and total cyanide in the leaked solution (225 mg/l and 250 mg/l, respectively) are the same as in the pregnant pond solution. Metal concentrations in the leaked solution at the point of leakage are approximately 30 mg/l iron, 5 mg/l arsenic, 1 mg/l cobalt, 1 mg/l gold, and 0.005 mg/l silver. The depth to ground water varies among sites from 6 to more than 100 meters (20 to more than 300 feet) below the ground surface. The nearest surface water is approximately 0.8 kilometer (0.5 mile) distant. Connections between the ground water beneath the pregnant pond and the surface water are unknown.

ISSUES OF CONCERN

This evaluation considers all of the issues of concern resulting from the placement of the hypothetical heap leach operation at the three sites in the northern Black Hills, including the issues resulting from the two accidental releases of cyanide solution described above. The significant issues evaluated to determine impacts from the cyanide heap leach facility include the following.

- . The effects the project will have on local water quality, particularly including increases in erosion and sediment production associated with mining activities and the possibility of cyanide spills and contamination.
- . The extent to which streams in the study area are receiving pollutants from past mining activities.
- . The provisions made to direct water away from the leaching pads, pit areas, and ponds.
- . The extent of reclamation and revegetation of disturbed areas.
- . The impacts of this project on the resident fisheries.
- . Whether the economic benefits of the project, including new jobs, purchasing, and tax revenues, will offset potential effects on local public services and utilities.
- . The long-term effects of the project on the local community lifestyle.
- . The extent of growth (population and economic) that can be expected.

The following sections address these issues by discussing the impacts of the hypothetical cyanide heap leach operation on the resources of the three drainages. Both construction and operational impacts and impacts resulting from the two accidental release cases are considered.

GEOLOGICAL RESOURCES

The three mines are located in the Tertiary intrusive belt located near the Lead Dome area. Ore will be mined from the Tertiary intrusives and associated Deadwood Formation in the mines along Whitewood Creek and Bear Butte Creek and from the Tertiary intrusives and the Pahasapa Limestone in the mine located in the Spearfish Creek drainage. The ore deposits are medium to small vein and replacement deposits.

The potential impact to the geological resources is the loss of the mineral resource due to mining. It is estimated that 13,500 metric tons (15,000 short tons) of ore and waste rock will be mined daily. The placement of waste-rock piles could inhibit access to ore in the future. Because mineral resources are finite, the waste rock and associated spent ore may eventually be further mined as mining technology advances and permit recovery of minerals from lower grade ores.

Potential impacts could also include mass failure. Mass failure occurs when large masses of earth material, such as soil, rock, or debris, are cohesively transported by gravity from one place to another. Potential areas for mass failure are the mining pit area, waste rock pile, haul roads, and leach pad site. By proper engineering and the siting of waste rock piles, haul roads, and pads in suitable locations, the potential for failure can be reduced or eliminated.

Impacts resulting from unavoidable alterations in topography would also occur. The significance of such alterations would be site-specific and would depend in large part on post-project land uses.

The accidental release of cyanide either by spilling or by leaking from the pregnant pond would not have significant impacts on the geological resources at any of the three drainages.

GROUND WATER

Mine Facility Construction and Operation

The major source of water for the mining operation in all three drainages would be ground water from wells and/or springs. The mining operation will initially use a large amount of water for process water. Because evaporation exceeds precipitation in this region, a small amount of water will continually be needed for additional process water. Water will also be required for normal plant operations such as plant facilities, domestic use, and road spraying. This use of ground waters may result in a lowering of the ground water table, which could adversely affect surrounding ground water users. Drawdown effects depend on the distance between wells, rates of pumping, and the aquifers used. Other ground water users will probably not be affected by the hypothetical mining operations, based on the remoteness of the locations for the mining operations and the lack of adjacent water users. However, the possibility of adversely affecting others who use ground water should be considered when evaluating actual proposed mine sites.

The recharge areas for the aquifers at all three sites occur along the aquifer outcrops. The 400 hectares (1,000 acres) disturbed by mining would not significantly affect recharge.

The mining operation will mine near-surface ore from an open pit. In some areas, the ground water table may be near-surface. If some of the ore in the pit is below the ground water table, measures should be taken to control ground water flow by pumping. The region is known to contain numerous springs, so it is possible that springs fed by near-surface aquifers disturbed by the mine pit may temporarily dry up or experience water quality changes. Runoff and any ground water (if present) will be pumped from collection sumps to a settling pond or will be used in dust control on roads and dumps. If unexpected mine dewatering problems are encountered during the course of mining, the mining plan may need to be modified.

If the ground water level beneath the heap pad and process area is near the surface, design and installation of underdrains will be needed to allow for flow of ground water. Heap stability in the case of near-surface saturated conditions should also be considered in the design.

During regular operations, the ground water quality of the three drainage areas will not be affected. The heap leach operation and processing plant have been designed and will be maintained as a totally contained, no-discharge system.

Spearfish Creek

The major aquifer at Raspberry Gulch, the tributary to Spearfish Creek where the mining operation will be located, is the Pahasapa Formation. The depth to ground water ranges from near surface to tens of meters (several hundred feet). The Whitewood Formation, a less prolific aquifer, may also occur in the area.

Ground water is used by summer residences along Spearfish Creek and the small developed areas near Deer Mountain and Terry Peak ski areas. Ground water use by the mining operation may potentially affect the alluvial aquifers used by the residences along Spearfish Creek since ground waters from the Pahasapa Formation are reported to discharge to the alluvium. The use of ground water by the mining operation may also affect the ground water use of nearby developed areas which are using the same carbonate aquifer. The impact of ground water use by the mine may be assessed by hydrologic tests to determine the drawdown in aquifers used by the mining operation. Four deep aquifer wells near Spearfish are used for the town's municipal water supply. The wells are completed in the Pahasapa Limestone and the Minnelusa Formation. It is unlikely, however, that drawdown from the mining operation would extend to these wells.

Whitewood Creek

Ground water may occur in several different aquifers in the Yellow Creek drainage, the tributary to Whitewood Creek where the mining operation will be located. Potential aquifers are the Whitewood and

Deadwood Formations, alluvium along Yellow Creek, and fractured Proterozoic metasedimentary and metavolcanic rocks. Ground water depths are estimated to be from near surface to tens of meters (several hundred feet).

Ground water use is limited in this area, which is located just west of the Grizzly Gulch tailings impoundment. The nearest development is Pluma where several residences are located. It is not known whether these homes are dependent on ground water for water supply. The towns of Lead and Deadwood obtain their water from springs. Withdrawal of ground water for the mine would not be likely to affect these low-volume users, but impacts would depend on which aquifers are used and the distance to adjacent water users.

The ground water quality of Yellow Creek may be of poorer quality than that of the other two drainages. The Wasp No. 2 Mine, the third largest mine in the Black Hills (refer to Chapter 3), is located in the Yellow Creek drainage. A hydrological study of both surface and ground water conditions would establish baseline hydrological conditions for this drainage.

Bear Butte Creek

Potential aquifers that may be used as a water supply for the mining operation in the Two Bit Creek drainage, the tributary to Bear Butte Creek, are the Pahasapa Limestone, Whitewood Formation, Deadwood Formation, and, possibly, Tertiary intrusives. Depths to ground water probably range from near surface to tens of meters (several hundred feet).

Several recreational residences may use alluvial ground water for water supply on Peedee Gulch and the headwaters of Two Bit Gulch. The impact of the mining operation's ground water use on the residences' alluvial supply will probably be minor, but will depend on which aquifers are used and the distance to adjacent water users. Deep water wells used by the town of Sturgis, which are completed in the Pahasapa Limestone and Minnelusa Formation, would be too distant to be affected by drawdown at the mining operation.

Accidental Releases

Of the two hypothetical releases, the pond overflow and leak, only the pond leak will affect ground water resources. Cyanide or metals from the pregnant pond overflow will not impact either the vadose zone or ground water. As a result of the pond leak, cyanide has been detected in the monitoring well downgradient of the heap leach and process areas. This discussion will focus on the factors which may affect the attenuation of cyanide in ground water, since there are not enough data to create a specific model for each drainage.

The following examples of leaks from heap leach mining operations are discussed to allow for quantification of the hypothetical pond leak. A spill and pond liner leak combination in Montana with 35 mg/l total cyanide and 27 mg/l chlorine amenable cyanide at the point of loss was detected in an alluvial well 0.40 kilometer (0.25 mile) away (Appendix D). The highest concentrations of cyanide detected in the well were 0.119 mg/l total cyanide and 0.14 mg/l chlorine-amenable cyanide which were detected 6 months after the accident. The cyanide has since dissipated. At a heap leach operation in Elk City, Idaho, 9 to 10 mg/l total cyanide and 1 mg/l weak-acid-dissociable cyanide were detected in a monitoring well (Appendix D). The concentration of the process solution that was the source of the leak is unknown. Apparently the cyanide had dissipated to below detection levels within 30 to 45 meters (100 to 150 feet) downgradient from where it had been detected in the monitoring well.

The movement and concentration of cyanide in the ground water from the leak at the hypothetical heap leach operation will be a function of the depth to ground water, dilution, characteristics of the soil and aquifer media, and the hydraulic conductivity of the aquifer. The chemical processes that control the transformation and reaction of cyanide depend on pH, temperature, concentration and types of metals present in solution and in the soils and subsequent formation of metal cyanide complexes, amount of aeration, and interaction with soil or rock particles (Appendix B).

The depth to water ranges from near surface to tens of meters (several hundred feet) at the three locations selected for the mining operation. If the pond site selected for the mining operation has near-surface ground water, there will be less chance for attenuation of cyanide through soil and/or bedrock in the vadose zone. Important processes for the attenuation of cyanide in the vadose zone may be volatilization, complexing with metal ions, biological degradation, dispersion, and possibly sorption. Volatilization and biodegradation may become less important with depth. The vadose zone medium in the mine site area will consist of a thin layer of soil and underlying bedrock.

The soil factors responsible for the attenuation of cyanide are clay content, soil depth, soil pH, content of hydrous metal oxides, presence of oxygen, and concentration of organic matter. The section on environmental impacts to soil from a surface spill discusses these factors in detail. No data exist on the attenuation of cyanide through different rock types. Based on the extrapolation of the soil data, rock types containing clays and hydrous metal oxides may attenuate cyanide more than those that do not. Once in the bedrock vadose zone, the specific type of bedrock will control path length and routing, which affects the time available for attenuation and the quantity of material encountered. The amount of fracturing or jointing will affect the routing.

If the cyanide reaches the ground water, the net recharge and the physical characteristics of the aquifer will be important controls on the amount of cyanide and its dispersion in the aquifer. Low recharge rates and low transmissivities would both result in little dilution and slow movement of the cyanide in the aquifer. The characteristics of the aquifer under the proposed mine sites are discussed in the following paragraphs.

The alluvial deposits are discontinuous unconsolidated stream channel, overbank, and flood deposits containing gravel, sand, and silt. Alluvial deposits such as channel deposits containing more

coarse-grained material (more permeability and less attenuation) have a greater potential for cyanide transport than deposits containing fine-grained materials. The potential exists for cyanide in the alluvium to be transported to underlying aquifers since they may be hydraulically connected. Alluvial ground water and surface water may also interact, possibly resulting in the introduction of cyanide into the surface water system.

Ground water in the carbonate aquifers (Pahasapa and Whitewood Formations), occurs in openings ranging from small pores, joints, and fractures up to large solution openings such as caverns. As with other bedrock aquifers, the extent of these openings influences the rate and extent of cyanide transport through the system. The Pahasapa Formation is recharged by precipitation, streamflow losses, and leakage from overlying aquifers at a net rate of 170 millimeters (6.8 inches) per year. This recharge rate is probably considerably greater than that of other bedrock aquifers in the Black Hills, so that a larger quantity of water may be available for dilution in this aquifer than in others. The cavernous portions of the carbonate aquifer may have high hydraulic conductivities, which have the potential for moving cyanide quickly away from the leak area and dispersing it through a large area. In addition, cyanide is more mobile in the higher pH ranges typical of carbonate aquifers than in aquifers having low pH values.

The sandstone aquifer, the Deadwood Formation, yields small to moderate amounts of good to saline water. The mobility of cyanide in the aquifer is largely controlled by both the degree of fracturing and the primary porosity of the sandstone.

Aquifers in the Proterozoic metasedimentary and metavolcanic rocks and the Tertiary igneous intrusives are metamorphic/igneous aquifers. These types of rocks have little or no primary porosity so that water can be obtained only from fractures within the rock. If wells are present in these aquifers, yields would be low. The relative mobility for cyanide in these aquifers is a function of the degree of fracturing.

SURFACE WATER

The effects of the mining project on surface water resources are primarily related to increased erosion and sedimentation caused by surface disturbance associated with mining and road construction activities, and potential accidental releases of hazardous chemicals. Specific areas of water quality concern include sediment production from roads and dump areas, heavy metal contamination, and cyanide spills.

Mine Facility Construction and Operation

During the construction phase of the heap leach facility, a short-term increase in sediment production would be an unavoidable effect. Increased erosion and sedimentation resulting from road construction and mine operation is expected to be controlled by the settling ponds, drainage diversions, and other standard sediment control structures.

Sizes and locations of haul roads affect the amount of sediment produced and the likelihood of it reaching a stream. Roads constructed on slopes or ridges away from stream channels can have half the sediment generating potential of streamside roads. Side casting of road material on steeper slopes (50 percent or greater) has the potential to greatly accelerate the erosion rate.

The waste dump area is also potentially a source of high sediment production and water quality degradation. The steepness of the terrain and the unpredictable nature of the runoff patterns require care in the selection of the disposal site. Any filling of natural channels would increase the potential for flooding, mass failure, and sedimentation problems. Hillside dumps may also be difficult to stabilize, could have a long-term adverse impact on water quality, and prove difficult to reclaim. Long-term erosion of waste rock piles and spent ore depends on configuration, susceptibility of coarse fragments to weathering, and revegetation success.

Accidental Releases

In the event of a spill of chemical-laden water from a mine structure (such as the overflow from the pregnant pond), the effect on surface water would depend on the amount of dilution and attenuation occurring. As discussed previously, cyanide from an actual spill at a concentration similar to that overflowing the pregnant pond at the hypothetical mine was reduced by two orders of magnitude as it flowed over the ground for 0.8 kilometer (0.5 mile). In this analyses, only dilution is used to reduce cyanide concentrations once the cyanide enters the stream since actual data on cyanide attenuation in streams are lacking. This is a conservative approach since many chemical and biological processes will continue to reduce free cyanide concentrations. Potential impacts of the pond overflow described earlier to Spearfish Creek, Whitewood Creek and Bear Butte Creek are discussed below by drainage.

In the event of a leak beneath the pond lining or heap, the primary release of cyanide would be to the ground water. Because of attenuation, it is unlikely that detectable concentrations of cyanide would be discharged from the ground water to the surface water. Discharge of cyanide from ground water to surface water would depend on the amount of attenuation in the vadose zone and in the aquifer, the distance traveled to surface water, and the amount of flow into surface water.

Spearfish Creek

At the Spearfish Creek drainage mine site, the spill of 100 cubic meters at 2.8 liters per second (27,000 gallons at 45 gallons per minute) would cross the vegetated ground surface for approximately 0.8 kilometer (0.5 mile) and enter Raspberry Gulch. Initially, the concentration of free cyanide in the spill would be approximately 200 mg/l. After flowing over the ground surface, the free cyanide concentration would be reduced by two orders of magnitude, based on the attenuation

factor discussed in Appendix D. The free cyanide content just before the spill entered the tributary (2 mg/l) would be about 2 orders of magnitude higher than the acute toxicity level for aquatic life (0.022 mg/l).

Raspberry Gulch flows for approximately 2 kilometers (1 mile) and enters Spearfish Creek. Assuming the average yearly high flow of Raspberry Gulch is about 0.1 cubic meter per second (5 cfs), the free cyanide concentration would be reduced an additional order of magnitude by dilution. Assuming an average yearly high flow in Spearfish Creek of 4.2 cubic meters per second (150 cfs), dilution upon entering Spearfish Creek would reduce free cyanide concentration by another order of magnitude in the range of acute toxicity level for aquatic life (0.022 mg/l). Dilution would reduce levels of cyanide in Spearfish Creek to below the chronic aquatic toxicity level of 0.005 mg/l further downstream from the Raspberry Gulch confluence. The town of Spearfish uses Spearfish Creek as a source of drinking water. Based on these assumptions, the cyanide content of Spearfish Creek at Spearfish will not exceed the EPA (1985) ambient water quality criterion for cyanide of 0.2 mg/l (free cyanide).

The process solution released also contains metal cyanide complexes and ions such as sodium and arsenic in solution. Arsenic does not form a metal cyanide complex. The concentration of arsenic, which would be diluted by more than two orders of magnitude would be below the EPA acute and chronic toxicity level for aquatic levels (0.36 mg/l and 0.19 mg/l, respectively) in Spearfish Creek immediately downstream from the confluence with Raspberry Gulch.

Most of complexed metal is iron, which forms a strong complex with cyanide. The concentration of iron is initially about 25 mg/l. Dilution would reduce this level by two orders of magnitude at Spearfish Creek just below its confluence with Raspberry Gulch to below the EPA aquatic life toxicity level for iron of 1 mg/l. Ultraviolet light may cause iron and cobalt cyanide complexes to photodecompose and release cyanide and free iron or cobalt. The rate of photodecomposition in deeper, turbid waters is not known. The half life for ferricyanide

($\text{Fe}(\text{CN}_6)^{3-}$) based on experimental data (Simovic et al., 1985) is 6.1 and 20.6 days for solutions at 4° C (39° F) and 20° C (68° F), respectively (refer to Appendix B, Table B-6). Assuming a stream velocity of 0.3 meter (1 foot per second) for the accidental spill discussed above, the spill would take about 2 hours to reach the mouth of Raspberry Gulch. Based on these data, the amount of free cyanide released from the degradation of ferricyanide as the spill travels downstream would be very small. No experimental data exist for cobalt cyanide complex, but probably the degradation rate would be similar to ferricyanide. Aquatic toxicity levels for cobalt have not been proposed by the EPA.

Other metals in the spill are gold and silver at concentrations of approximately 1 mg/l and 0.004 mg/l, respectively. These metals form strong complexes with cyanide. Conservatively estimating the concentration of the metals released from the metal cyanide complexes based only on dilution, concentrations of gold and silver would be reduced by 2 orders of magnitude at Spearfish Creek just downstream from its confluence with Raspberry Gulch. Aquatic toxicity levels for gold have not been proposed by the EPA. However, gold is very non-reactive and generally has a very low toxicity for biota. Assuming the silver cyanide complex completely dissociates to free silver, the content of silver in Raspberry Gulch would be below the EPA acute toxicity level for aquatic life of 0.013 mg/l. In Spearfish Creek downstream from the confluence with Raspberry Gulch, the silver content would be below the EPA chronic toxicity level for aquatic life of 0.00012 mg/l. The free cyanide released from the gold and silver complexes would be insignificant considering dilution.

Whitewood Creek

For a spill occurring on Yellow Creek, a tributary to Whitewood Creek, the environmental effects would be similar to those in Spearfish Creek. The distance between the site of the described spill and the confluence of Yellow Creek with Whitewood Creek is about 3 kilometers (2 miles).

Concentrations of free cyanide and metal cyanide complexes from the spill in Yellow Creek, with an assumed yearly high flow of 0.4 cubic meters per second (15 cfs), would be diluted by approximately two orders of magnitude. Assuming an average yearly high flow of 5.5 cubic meters per second (200 cfs) and 3.5 cubic meters per second (125 cfs) for Whitewood Creek at Deadwood and at Whitewood, respectively, free cyanide from the spill would be reduced in Whitewood Creek to below both the acute and chronic aquatic toxicity levels in the reach downstream from the confluence of Yellow Creek and the town of Deadwood.

Past and ongoing mining activities may contribute cyanide to Whitewood Creek. U.S. Geological Survey data (1983) in the vicinity of the town of Whitewood show total cyanide concentrations ranging from less than 0.01 mg/l to as high as 0.24 mg/l total cyanide (filtered sample). No sampling was done in the Deadwood area during the same time period. Homestake Mining Company has a permit for Whitewood Creek above Deadwood to discharge a treated waste stream containing 1.8 mg/l total cyanide from their wastewater treatment plant. The contribution of cyanide from the spill would not be noticeable when compared to background levels.

Impacts from metals and cyanide released from metal cyanide complexes at Raspberry Gulch would be very similar for Yellow Creek. If metals were released from iron and silver cyanide complexes in the spill, the concentrations of iron and silver in Yellow Creek upstream from its confluence with Whitewood Creek would be below toxicity levels for aquatic life. No aquatic toxicity levels for cobalt or gold have been proposed by the EPA. Arsenic levels in Yellow Creek from the spill would be below EPA toxicity levels for aquatic life. Background levels of arsenic, however, may be elevated because of past mining activities. For example, the dissolved arsenic concentration of Whitewood Creek in the vicinity of Whitewood ranges from less than 10 to 62 mg/l (U.S. Geological Survey, 1983). Effects of arsenic from the spill would be undetectable compared to background levels of arsenic in the drainages.

Bear Butte Creek

A spill from a mining operation located in Two Bit Creek would flow into Boulder Creek, and then into Bear Butte Creek. The effects would be similar to those discussed for the other two drainages. The spill would flow into Two Bit Creek, which has an average yearly high flow of 0.4 cubic meters per second (15 cfs), and travel downstream for about 3 kilometers (2 miles) to the confluence with Boulder Creek, which has a high flow of 0.3 cubic meters per second (10 cfs) above the confluence. Boulder Creek joins Bear Butte Creek after about 2 kilometers (1 mile). The level of free cyanide downstream from the mouth of Two Bit Creek would be reduced by approximately four orders of magnitude from the original spill, with a reduction of two orders of magnitude resulting from dilution and two orders of magnitude resulting from attenuation during overland flow. The free cyanide content would be in the range of the acute toxicity level for aquatic life (0.022 mg/l). The flow of Bear Butte Creek downstream from the Boulder Creek confluence is about 1 cubic meter per second (40 cfs) during high flow. Bear Butte Creek has an average yearly high flow of about 3 cubic meters per second (100 cfs) at Sturgis, which is approximately 8 kilometers (5 miles) downstream from the Boulder Creek confluence. Based on dilution only, free cyanide below Sturgis would be reduced to a concentration in the range of the chronic toxicity level for aquatic life.

The impacts of metal cyanide complexes and arsenic would generally be the same as for Spearfish and Whitewood Creeks. If the metal cyanide complexes (iron and silver cyanide complexes) dissociate and release metals, the levels of iron and silver would be reduced by dilution to below levels toxic to aquatic life in Two Bit Creek upstream from its confluence with Boulder Creek. No aquatic toxicity levels for cobalt or gold have been proposed by the EPA. Small amounts of free cyanide will also be released and be diluted to below toxic levels. Arsenic levels in Two Bit Creek from the spill would be below EPA chronic toxicity levels (0.19 mg/l).

SOILS

Mine Facility Construction and Operation

Soils impacts resulting from construction of the cyanide heap leach and processing facilities will be similar in type and magnitude in all the three drainages because of similarities in soil and topographic characteristics. The major impacts to soils will result from removal, compaction, or other in-place disturbance of soils during the construction of the facility. In this example, 400 hectares (1,000 acres) will be disturbed.

Suitable growing material (topsoil) varying in depth from 40 to 150 centimeters (15 to 60 inches) will be stockpiled and protected from erosion for subsequent use during reclamation. Assuming a soil removal depth of between 46 and 91 centimeters (18 and 36 inches), between 1.2 and 3.7 million cubic meters (1.6 and 4.8 million cubic yards) of material could be removed and stockpiled during the project life.

Soil resource values potentially affected by mine development include alteration of soil structure, compaction, interruptions in soil microbial activity, erosion by wind and water, changes in soil nutrient status and fertility, and reduced vegetation restoration potential. Dramatic disturbance in the inherent soil structure by removal or compaction during construction, could result in reduced water infiltration rates, disruptions of nutrient cycles and microbial activity, and increased erosion hazards. The effects would be temporary until stockpiled and compacted soil was reclaimed and/or revegetated. Root development and increased microbiological activity would improve soil structure and enhance vegetative growth.

When the litter layer is completely removed during facility construction, or compaction is caused by vehicle movement, water infiltration into the soil is decreased. This will produce a greater amount of overland flow and, hence, more runoff energy will become available to produce surface soil erosion (U.S. Environmental Protection Agency, 1980). Without appropriate sediment-control structures, this increased soil loss could become a major source of non-point

pollution (Fredriksen, 1972). Nutrients essential to plant growth will be less solubilized because of reductions in soil moisture caused by compaction. The impacts of soil disturbances on vegetation restoration potential will be temporary if controlled. However, if construction activities result in excessive losses of soil, reduced nutrient levels, and a decline in soil structure, long-term, significant impacts to plant community restoration potential could occur.

Certain portions of the mine pit will not be reclaimed. Therefore, these areas will experience long-term, possibly irreversible losses of soil resources. Areas slated for reclamation following the life of the project will experience only short-term effects.

Accidental Releases

The effects on soils as a result of the pond overflow would be limited to the immediate area of overland flow. As discussed in surface water, cyanide is reduced by dilution in the major streams so that there would be little, if any, effect on downstream flood plain soils. In investigations of actual spills, little cyanide was detected in the soil.

Some of the spilled process water may infiltrate into the soil. However, because most of the soil profile would still be frozen during the spring snowmelt period when the spill occurred, infiltration would be limited. If most of the soil profile had thawed, the depths of infiltration would depend on soil permeability and soil depth. The dominant soils at all three locations have permeabilities ranging from low to moderate (10^{-2} to 10^{-6} centimeters per second). The soils are approximately 150 centimeters (60 inches) deep.

If the spill enters the soil zone, the mobility of cyanide will depend on characteristics of the soil such as the clay depth, pH, existence of aerobic or anaerobic conditions, presence of soil organic matter, and content of hydrous oxides (Fuller, 1985). Appendix B provides a general discussion of cyanide movement in the soil. The clay content in the surface horizons most susceptible to contact with cyanide ranges from 7 to more than 20 percent in the three drainages.

Many of the clays are kaolinitic in nature, which would tend to reduce mobility of cyanide more than montmorillonitic clay (Huiatt et al., 1976). Montmorillonite clays are more abundant at deeper depths within the soil profile. Clay content increases with depth, further immobilizing cyanide.

Volatilization of hydrogen cyanide will occur in soils at the three sites, since the pH of the soils ranges from neutral to moderately alkaline. Cyanide will be more mobile in soils with the higher (more alkaline) pH values. The absence of calcium carbonate in large quantities in the upper 25 to 30 centimeters (10 to 12 inches) of most study area soils would also aid in immobilizing cyanide. Should cyanide infiltrate to below this depth, calcium carbonate may activate the cyanide ion (Alesii and Fuller, 1976).

The soil conditions at the three sites are aerobic. Under aerobic conditions, cyanide will move only a short distance before being biologically converted to nitrate (Huiatt et al., 1983). Organic matter on the surface will attenuate cyanide, promoting rapid breakdown by micro-organisms.

The content of iron oxides in the soils is insignificant in the Bear Butte and Spearfish Creek drainages, and will not greatly influence cyanide mobility. Iron content is higher in the lower Whitewood Creek drainage. The presence of iron and its influence on cyanide movement is minimal, however, at the Whitewood Creek site.

The metals, iron, arsenic, gold, silver, and cobalt, in the spilled process solution will have little impact on soil. The concentrations of the metals will be far below levels considered toxic to plants or animals (U.S. Environmental Protection Agency, 1983). Most of the arsenic will be bound by clays, hydrous iron oxides, and organic matter in the surface horizons of the soils at the three sites.

The soil conditions in the study area suggest that movement of cyanide and its complexes will be rapidly attenuated at all three sites. Additionally, the effects of the spill on soils would be localized and not extend off the project site. Discharges at the three

sites, based on the best available information presented in Appendix B, could cause insignificant short-term increases in soil pH and decreased microbial activity. Permeability and structure may not be affected because the example spill occurs in the early spring under near-frozen soil conditions. Long-term productivity of vegetation or soil microbial populations would not be impaired. Nutrient levels in soils should not be affected either in the short or long term. Water quality also will not be affected by an increase in the levels of cyanide in soil because of the many processes that degrade cyanide as it makes contact with the soil.

In the example of the pond leak, an undetected plume of pregnant pond solution seeps into the ground water. During construction, all soil suitable for use as a growing medium has been removed near or to bedrock. Therefore, impacts to soils in the plant root zone (solum) are not significant, as these soils have been removed and stockpiled for later reclamation. The effects on the soil remaining beneath ponds or heap pads are a function of the factors discussed in the pond overflow example. Some examples of leaks at heap leach mining operations provide an estimate of the extent of soil impacts. At the American Mine, liner failures occurred and free cyanide concentrations of up to 300 mg/l were measured in soil cores below the ponds. The maximum depth of free cyanide detection was 61 centimeters (24 inches). Maximum soil penetration of cyanide was approximately the same below leaks in PVC liners under inactive heaps at the same mining operation.

VEGETATION

Mine Facility Construction and Operation

General vegetation impacts resulting from construction of mining and process facilities in the Spearfish Creek, Whitewood Creek, or Bear Butte Creek watersheds would be similar for each drainage. Construction would directly affect vegetation through removal or through partial destruction by construction equipment and other vehicles. In this example, approximately 400 hectares (1,000 acres) of native vegetation could be affected in each watershed.

Vegetation resource values potentially affected by mine development include plant productivity, nutrient cycling, microclimate influences, habitat, ecosystem structure, erosion control, and esthetics. Based on regional relative abundances of vegetation types, the majority of the effects would result to ponderosa pine forests. Several acres of mountain grassland or riparian vegetation could also be affected.

Operational effects of heap leach mining on vegetation could result from wind-blown cyanide spray from the heap leach pile. However, the spray process would probably be halted during strong winds so the effect of cyanide spray on vegetation should be negligible.

Standard reclamation and revegetation practices would serve to reduce the effects of the project. However, because only portions of the mine pit would be reclaimed, residual impacts on vegetation resources would remain. Construction of roadways, ponds, and other minor facilities could also result in impacts on vegetation throughout the life of the project. Disturbance associated with pipeline burial, transmission tower construction, and slopes adjacent to access routes would be revegetated soon after construction. Therefore, only short-term impacts resulting from direct disturbances would be associated with these activities.

Secondary impacts associated with human population growth and activity could significantly affect vegetation resource values outside the mining area as a result of urban expansion, accidental range and forest fires, and increased off-road vehicle (ORV) use.

If project facilities are developed in or adjacent to stream tributaries, direct and secondary effects on plant species of special concern could occur. Rare plant species could occur along watershed drainages. Direct disturbances to these plant populations or changes in surface water quality or quantity could reduce their viability or numbers. Locations of populations of special concern plant species should be considered in project planning and design.

Accidental Releases

The hypothetical leak in the pond liner which results in contamination of the ground water under the pregnant pond should have an insignificant impact on vegetation resources. If the depth to ground water is less than 40 feet, some trees and shrubs with roots near or in the ground water aquifer could come into contact with the affected ground water. However, cyanide concentrations in ground water would be rapidly attenuated. Therefore, the adverse effects on vegetation would be localized and minimal. By the time the ground water reached the surface water bodies, the concentrations of cyanide would be below those harmful to plants.

The hypothetical pond spill would result in 100,000 liters (27,000 gallons) of pregnant pond solution flowing overland 0.8 kilometer (0.5 mile) to a tributary. Many physical and environmental factors would influence the effects of the spill on vegetation. Cyanide concentrations could be rapidly attenuated by the soil. Slope characteristics, plant density, and plant community composition would affect the rate of overland flow and the extent of vegetation affected. It is probable that vegetation in the immediate vicinity of the spill source would be adversely affected, as discussed in Appendix C. Concentrations of 200 mg/l cyanide could result in complete or partial loss of plants in the immediate area (Stanton et al., 1985). Depending on the plant species present and the concentration of cyanide reaching the waterway, riparian vegetation and plant species of special concern occurring immediately adjacent to the stream could also be adversely affected. The concentrations of cyanide and physiological effects of cyanide on plants are discussed in Appendix C. By the time the solution reached agricultural areas at lower elevations in and adjacent to the Black Hills, concentrations of cyanide would be reduced to levels that would not be toxic to crops.

WILDLIFE

Mine Facilities Construction and Operation

Potential effects resulting from the construction and operation of the heap leach mine operation could include habitat removal, habitat degradation, and direct wildlife mortality. Habitat removal refers to the loss of available habitat through conversion of present land uses to other uses. Habitat degradation occurs when habitat is left in place but its quality is reduced. Factors affecting habitat quality include decreased water quality and increased noise, human presence, and soil erosion. Direct mortality results from increases in legal and illegal hunting, road kills, and exposure to toxic chemicals.

Approximately 400 hectares (1,000 acres) would be stripped of vegetation and converted to project uses for the life of the project. The effects of this conversion would depend on the actual project layout (a solid block or dispersed areas connected by roads), vegetation types present, areal extent of each vegetation type, local wildlife assemblage, and the presence of unique wildlife species, habitats, and features. Generally, loss of vegetation causes a reduction in local wildlife populations associated with the removed vegetation.

Because ponderosa pine would probably account for most of the vegetation loss at all three sites, the removal would primarily affect wildlife associated with ponderosa pine, such as deer, porcupines, red squirrels, turkeys, and red-tailed hawks. The effects on wildlife species associated with the other vegetation types occurring in the Black Hills environment would depend on how much of each type is removed. Each of the three sites are located in winter range. The Yellow Creek and Two Bit Creek sites are also located in year-round elk range. Species of special concern associated with upland vegetation types, such as mountain lion and black bear, could also lose habitat to land use conversion if they occur on any of the sites.

The effects of the removal of 400 hectares (1,000 acres) of wildlife habitat for the duration of the project could range from insignificant to potentially significant for all three sites depending

on the wildlife group present. For most species and wildlife groups, the loss would probably not be significant because they occur in a variety of vegetation types and are widely dispersed, highly mobile, and abundant. However, the loss of 400 hectares (1,000 acres) of critical deer winter range and elk range could be significant because both are limited in the area. Their loss could reduce the potential for these popular game animals to maintain or increase present herd sizes.

If any species of special concern occurs on the sites, the conversion of its habitat to project uses could be significant. Habitat loss is one of the primary causes of the population decreases experienced by most special concern species. In addition, limited available habitat is one of the factors restraining the expansion of many special concern populations.

General degradation of habitat around the mine would be similar for each site. Construction of diversion ditches and sediment ponds is expected to prevent or mitigate soil erosion and its associated water quality impacts on wildlife. Increases in noise and human presence generally elicit an avoidance response in wildlife. This response is more pronounced in some species such as deer, elk, and some species of special concern such as eagles. The potential for habitat degradation may be relatively greater at the Two Bit Creek site because there is currently less human development in that watershed than in the other two watersheds where the hypothetical mine is located.

Elk are widely recognized as being sensitive to human disturbance. The intrusion of roads, recreation areas, and mining, logging, and hunting activities into otherwise attractive habitat can displace elk. The magnitude of this displacement can be quite large. Studies of elk movement and habitat utilization responses to human disturbance suggest that elk maintain a buffer zone of approximately 500 to 1000 meters (550 to 1100 yards) around the human disturbance (Ward et al., 1978; Edge and Marcum, 1985; Lyon et al., 1985). Therefore, where main-

tenance of elk habitat quality and security is an important consideration, adequate buffer zones around human disturbances are important considerations in maintaining habitat integrity.

The effects of increased noise and human presence at each site could range from insignificant to significant depending on factors such as project facility layout (one large area or several dispersed areas with roads between), the number of sensitive species (deer, elk, and species of special concern) using the site and surrounding areas, available buffer zones, and the amount of noise and general disturbance. Deer could be affected at all three sites while elk could potentially experience impacts at the Yellow Creek and Two Bit Creek sites. If any species of special concern occur on the sites, habitat degradation could cause sensitive species to abandon the immediate area. This abandonment would have the same results as habitat removal. Therefore, effects of habitat degradation on species of special concern using the sites could be significant.

Direct mortality increases are not expected to significantly affect wildlife at any of the three sites. Only relatively minor increases in road kills and hunting mortality are expected from the slight human population gain.

Once the mine and processing facilities are in operation, unrestricted access to the heap and open ponds could cause some loss of wildlife due to consumption of cyanide solution. However, the proposed fencing of the heap, ponds, and processing area, flagging of the barren and pregnant ponds, and filling of collection ditches with rock will minimize access to and subsequent consumption of the cyanide solution by wildlife. Therefore, intoxication from the cyanide processing facilities should pose little threat to wildlife at any of the three sites.

Wildlife may be exposed to potentially toxic concentrations of cyanide (250 mg/l total cyanide) through wind drift during the spray application of solution. The degree of this exposure depends on the strength and direction of the wind (which determines the volume and

distance the solution is carried outside the processing area), time of day, and season (which influences which wildlife species may be present). Wind drift will probably not be a significant pathway for wildlife exposure because operators generally turn the sprayers down or off during windy conditions to prevent the loss of their leaching solution. This action would limit the amount of drifted solution that would be available for ingestion.

Accidental Releases

The leak from the pregnant pond liner would not produce any impacts to wildlife species in the area. The leaked solution could enter the ground water system but would be unavailable to wildlife species. If the contaminated ground water eventually discharged to surface water, the toxic substances would be sufficiently diluted and attenuated so as to not pose any threat to wildlife.

In the case of pregnant pond overflow, two types of solution components could be of concern. The spilled solution consists of free cyanide, metallic cyanide complexes, and arsenic. Small amounts of dissolved forms of heavy metals (cobalt, iron, silver, and gold) may be released from the metallic cyanide complexes. Potential effects of cyanide and the metals are discussed below. The number of wildlife species and individuals exposed to potentially toxic levels of contaminants from the overflow are variable and difficult to determine without site-specific information.

Cyanide

Effects of cyanide on wildlife are described in Appendix C. Lethal threshold concentrations vary among species tested. Free cyanide at 3.0 mg/kg and 0.1 mg/kg were reported to be toxic to mice and birds, respectively. However, rats fed diets containing as much as 1,500 ppm potassium cyanide showed few signs of toxicity (Feigley et al., 1985). Research with dogs indicates that large doses of sodium cyanide (0.5 to 2.0 mg/kg) administered periodically are tolerated. These results, combined with the observations that cyanides are not accumulated or stored and that many species of plants commonly eaten by

wildlife synthesize cyanogenic glycosides (Appendix B), suggest that animals are able to metabolize and detoxify both free and complexed cyanide.

The spilled process solution at each site crosses about 0.8 kilometer (0.5 mile) of vegetated ground and enters a flowing tributary. The concentration of free cyanide (initially 200 mg/l) is reduced two orders of magnitude, to about 2 mg/l, by the time it enters a creek. Upon entering Raspberry Gulch, Yellow Creek, or Two Bit Creek, the concentration is further reduced by dilution. Based on threshold concentrations reported in the literature (Appendix C) only the overland flow of solutions would contain concentrations of cyanide that could measurably affect wildlife. Therefore, only the overland flow is discussed further.

The primary pathway for wildlife exposure would involve animals drinking the solution. Virtually any species that occurs near the sites could come into contact with the solution during its period of overland travel. Large mammals, furbearers, small mammals, and songbirds would be the wildlife groups most likely to be affected because they are the groups most likely to come into physical contact with and drink the overland flows of solution. Songbird exposure would be minimal if the overflow occurred at night when most birds are inactive. Effects could range from minor to lethal, depending on the species, its threshold tolerance, the volume of solution ingested, and point of contact. Point of contact is important because the free cyanide concentration decreases from 200 mg/l to about 2 mg/l as it flows across the 0.8 kilometer (0.5 mile) of upland habitat.

Metals

Of the five metals that may occur in the cyanide solution, only arsenic would cause concern to wildlife species. Iron, cobalt, gold, and silver present few hazards to wildlife because they are either relatively nontoxic to warm-blooded animals or they have extremely low solubility characteristics and are essentially immobile.

Although documented wildlife-related effects of arsenic toxicity are rare (Demayo et al., 1979), livestock mortality associated with the consumption of arsenic-contaminated soils and/or vegetation (Gough et al., 1979) and public health problems associated with the consumption of contaminated water by man have been reported. Arsenic compounds do not accumulate in mammals (Vallee et al., 1960). Differences in arsenic toxicity do exist and have been correlated with animal excretion rates; compounds that are slowly excreted tend to be the most toxic (Vallee et al., 1960). The biological half-life for excretion of arsenic compounds are reported to range from 30 to 60 hours (Sullivan, 1969). The lethal dosage of arsenic for sheep has been reported as 3.4 ppm (Berry and Wallace, 1974) while the acute lethal dose for rats is 13 ppm (Sullivan, 1969).

The concentration of arsenic in the leaked solution (4 mg/l) would be diluted by one order of magnitude as it entered Raspberry Gulch by two orders of magnitude as it entered Yellow Creek or Two Bit Creek. This reduction would result in concentrations that are below toxic levels to wildlife. Therefore, as with cyanide, the overland flow would be of primary concern.

The primary pathway for wildlife contamination from the overland flow would be drinking contaminated water. Effects would depend on the amount ingested, species involved, the chemical form of the arsenic, and the arsenic concentration of the ingested solution. Wildlife groups most likely to drink the solution include large mammals, furbearers, small mammals, and songbirds. Effects are not likely to be lethal, based on the low initial concentration and dilution. Secondary contamination via the food chain is not likely because arsenic compounds have not been shown to accumulate (Vallee et al., 1960).

AQUATIC RESOURCES

Mine Facilities Construction and Operation

Soil erosion caused by construction of roads and ponds, open pit excavation, and disposal of waste rock should be minimal if sediment

control methods are implemented. Surface runoff at the pit would be collected by inward-sloping benches; sedimentation from exposed mine areas and the waste dump fill would be controlled by a sediment collection ponds; road runoff would be directed to adequate culverts; cut and fill slopes from road construction would be revegetated early; and roads would be located away from streams where possible. These measures are ideal practices which may not be consistently and fully implemented in all cases. Furthermore, the first phases of construction, before erosion-prevention measures can be implemented, would create areas of erosion and could cause increased sediment loading to streams. However, once erosion-preventing practices are installed, sediment loading to streams would be minimized.

Suspended sediment can suffocate aquatic organisms that are adapted to clear water such as those found in Spearfish and upper Whitewood Creeks. Increased sediment loading can also degrade the substrate upon which macroinvertebrates live and which is used by many cold-water fish species, such as trout, for reproduction. The sediment settles between and on top of larger particles. This suffocates organisms that live underneath the particles and eggs that are laid between the particles and degrades surfaces on which stream organisms cling and feed.

The boundaries of each of the three hypothetical sites contain one or more streams. Potential disturbance areas of Raspberry Gulch are within 2.4 kilometers (1.5 miles) of Spearfish Creek, which could receive some of the increased sediment loading from Raspberry Gulch during high-flow periods. Impacts to Raspberry Gulch could be reduced if existing roads were used and mine operations were located on the more level area of Dutch Flats. Sediment from the Yellow Creek site could enter Whitewood Creek directly, or high flows could transport sediment through Yellow Creek to Whitewood Creek, a distance of about 2.4 kilometers (1.5 miles). Potential damage to these creeks could be reduced by using the existing roads and maintaining a buffer between

mining operations and the drainages. Operations at the Two Bit Creek site could affect Two Bit Creek, an intermittent stream, but would be too far from Bear Butte Creek to affect it.

Accidental Releases

An overflow of the pregnant pond would release free cyanide and metallic cyanide complexes. Free cyanide is much more toxic than metallic cyanide complexes. The concentration of the free cyanide in the spill would be 200 mg/l, but would be reduced by attenuation and dilution to approximately 0.2, 0.02, and 0.02 mg/l upon reaching the mouths of Raspberry Gulch, Yellow Creek, and Two Bit Creek, respectively. The levels of cyanide in these creeks would be in the range of acute toxicity to fish. Because the cyanide would come from an accidental spill and because cyanide attenuates rapidly, this source of cyanide would not subject the aquatic community with chronic exposure to free cyanide. Although Raspberry Gulch and Two Bit Creek are intermittent (according to U.S. Geological Survey maps), they may be used by fish during spring snowmelt, the conditions under which this example was constructed. Under these conditions, significant short-term impacts to the aquatic community of these tributary creeks would occur. These impacts could include the loss of all fish life and much of the macroinvertebrate life in the creek.

Because of dilution, the cyanide concentration which would occur in Whitewood Creek due to spills in Yellow Creek would not pose a threat to aquatic life. However, a concentration of 0.02 mg/l of cyanide, which was predicted for Spearfish and Boulder Creeks downstream from Raspberry and Two Bit Creeks, respectively could be harmful to reproduction of fish and growth of juvenile fish. However, exposure of fish to this level of cyanide for at least 15 days would be required for impacts on fish reproduction or growth to occur and the spilled cyanide would pass through the stream system within a few hours.

One of the degradation products of cyanide is ammonia, which in its un-ionized form is highly toxic to forms of aquatic life. As the cyanide degraded, ammonia concentrations in the receiving streams could increase. The concentrations of un-ionized ammonia could exceed toxic levels and fish kills could result. Additional study would be required to determine the likelihood of this impact.

The spill also contains metals complexed with cyanide (iron, cobalt, gold, and silver) and arsenic. Aquatic toxicity levels for cobalt and gold have not been proposed by the EPA. If the metal cyanide complexes released metals and free cyanide, the iron and silver concentrations of Yellow and Two Bit Creeks would be diluted to below toxicity levels for aquatic life. At Raspberry Gulch, however, iron and silver concentrations would not be reduced to below chronic toxicity levels until additional dilution was provided by Spearfish Creek. The amount of free cyanide released from the metal cyanide complexes would be very small since stable metal cyanide complexes degrade very slowly (see discussion in surface water). Arsenic levels in both Yellow and Two Bit Creeks would be below aquatic life toxicity levels. At the Raspberry Gulch site arsenic would not be reduced to below chronic toxicity levels until additional dilution was provided by Spearfish Creek.

The leak from the pregnant pond liner would not produce any impacts to aquatic biota in the area. If ground water was contaminated and eventually discharged to surface water, the toxic substances would be sufficiently diluted and attenuated so as to not pose any threat to aquatic biota.

A spill from the neutralization pond during site closure could also be a hazard to aquatic life. Chlorine is commonly used in the neutralization process, and both it and chlorocyanide are extremely toxic to aquatic life. The 96-hour lethal concentration for 50 percent of the test organisms (LC_{50}) has been reported to range from 0.014 to 0.029 mg/l residual chlorine for trout (U.S. Environmental Protection Agency, 1976) and from 0.09 to 0.30 mg/l for some warm water species. Gammarus, an amphipod, exhibited reduced survival at 0.05 mg/l residual

chlorine and reduced reproduction at 0.0034 mg/l residual chlorine. Chlorine attenuates rapidly but the possibility of significant adverse impacts to aquatic life from residual chlorine in an accidental release from the neutralization pond exists, depending on the placement of the neutralization pond in relation to streams.

SOCIOECONOMICS

Evaluation of impacts on the social and economic environment differs from analysis of effects on natural systems in two major ways. First, impacts on natural systems are almost entirely direct impacts; that is, impacts resulting from the physical activity of the mining operation itself. Although there are similarly direct socioeconomic effects of mining operations, such as employment at the mine and property taxes generated by the capital investment in the mine site, there are also numerous indirect impacts such as employment generated in other sectors of the local economy resulting from purchases of goods and services by both the mine operator and by households of employees at the mine, and sales taxes generated by these expenditures.

The second major difference between socioeconomic and natural resource impact analyses is that most impacts to the natural environment take place (at least initially) on or in close proximity to the site of the mine operation, while most of the socioeconomic impacts occur offsite. For example, employees of the mine typically live, purchase consumer goods and services, pay taxes, and demand public services in communities at locations distinct and separate from the site of the mining operation. Therefore, forecasting of socioeconomic impacts typically requires definition of a study area covering a broader geographic region than might be required to assess other environmental impacts.

Project Direct Employment and Income

The driving force of many of the socioeconomic impacts generated by a mining operation is employment at the mine. For impact assessment purposes, it is assumed that the mining operation would have a 12-year

life span with the first 2 years consisting of construction activity. Employment is estimated at 35 workers the first year, 70 in the second year and 100 employees thereafter throughout the life of the actual mining operation. Closing of the ore producing operation would then be followed by reclamation. It is anticipated that major reclamation activity, employing approximately five individuals, would continue for about 1 year after shutdown with an undetermined, low level of effort thereafter until reclamation was complete.

Based on an estimated annual income of \$25,000 per permanent employee or mine construction worker, these employment levels would generate personal income of \$875,000 in the first year, \$1.75 million in the second year and \$2.5 million in years 3 through 12 of the mine operation. In year 13, income of \$125,000 could be expected as a result of reclamation efforts.

A basic to non-basic income multiplier of 1.6 and a basic to non-basic employment multiplier of 2.0 is assumed for Lawrence County. This indicates that each additional \$1.00 of income in a basic industrial sector such as mining will generate an additional \$0.60 of income in non-basic sectors in the county. Each additional mining job will result in one new non-mining job, for a total of two new jobs added to the local economy. This multiplier effect primarily results from jobs created to satisfy the demand for goods and services generated by the mine itself and by mine employees. Therefore, total additional employment generated during the period of full operations would be 200 jobs, while \$4 million in personal income would be added to the local economy annually. These impacts on employment and income over the anticipated duration of mine operations are summarized in Table 39.

TABLE 39
ANNUAL EMPLOYMENT AND INCOME GENERATED BY
HEAP LEACH GOLD OPERATION

	<u>First Year</u>	<u>Second Year</u>	<u>Years Three Through Twelve</u>	<u>Year Thirteen</u>
Project Direct Employment	35	70	100	5
Secondary Employ- ment	<u>35</u>	<u>70</u>	<u>100</u>	<u>5</u>
Total Employment	70	140	200	10
Project Direct Income	\$ 875,000	\$1,750,000	\$2,500,000	\$125,000
Secondary Income	<u>525,000</u>	<u>1,050,000</u>	<u>1,500,000</u>	<u>75,000</u>
Total Annual Income	\$1,400,000	\$2,800,000	\$4,000,000	\$200,000

In addition to the impacts from mine employment and income, there would be economic benefits resulting from mine purchases of materials, goods, and services such as office supplies, furniture, vehicle parts, and fuel, oil, and lubrication grease for mining equipment. After an initial development investment in the mine, operational expenditures of this nature are estimated at \$1.2 to \$2 million annually. Up to 50 percent of these recurrent purchases could be made locally, resulting in a \$600,000 to \$1 million boost in sales for the local economy. The capital investment, mineral production, and purchases generated by the mining operations will generate property, severance, and sale tax revenues for state and local governments (Wharf Resources, 1985).

Project-Related Population

The additional employment generated by the mine operation will impact population levels in the county. Based on the recent experience of other mine operators, it is expected that up to 80 percent of mine employment will be recruited from within Lawrence County. Assuming that this rate would also apply to additional non-mining employment secondary to the mine operation, 160 additional jobs would be provided for Lawrence County residents. Based on an estimated labor force participation rate of 1.2 workers per household and an average household

size of 2.7 persons, this would translate to 133 resident households and 360 persons associated with the project from among the region's current population. This increase in local employment would be expected to have some impact on stemming out-migration from the Lead-Deadwood area.

An additional 20 percent of the jobs generated by the mine operation would be filled by in-migrants from outside the county. This would translate to 33 households with a total population of 90 persons. Based on residential patterns of present mine workers, about one-half of these workers would reside in the Lead-Deadwood area, about 20 percent in Spearfish, and the remainder in outlying areas of the county and in adjoining counties. This would result in about 17 households and 45 persons seeking residences in Lead and Deadwood. This would also translate to some additional demand for services provided by local governments. The impact of these demands on local government expenditures and revenues is addressed in the section on fiscal impacts.

Indirect Impacts

Employment

The direct employment impact of a gold heap leach facility will be 35 to 70 positions during project construction, increasing to 100 jobs over the life of the mine. Because of the similarity of skills and occupations required for the construction and operation phases of the facility, many of the construction workers will be retained as part of the permanent work force. Although actual leaching operations are only anticipated to occur during a 9- to 10-month period, ceasing during the coldest winter period, direct project employment will remain relatively constant throughout the year. This will be accomplished through reassignment of personnel to annual maintenance activities, preliminary mine pit preparation, and waste dump management.

Including the indirect employment impacts, the total effect on employment is estimated at 200 jobs. These will either be net additional employment opportunities or preservation of existing jobs.

Based on the expected residency pattern of the project direct employment, 70 to 75 percent of the total jobs will be available within the Lead-Deadwood local area of influence. The remainder will be distributed between the Spearfish and Sturgis areas, which provide retail trade shopping opportunities and consumer services for their respective market areas including the Lead-Deadwood area. Compared to total current employment of nearly 9,000 and mining employment of approximately 1,500 to 1,600, this impact, although moderately beneficial, will not be significant.

The project's effects on overall local employment patterns will not vary greatly with each mine site alternative. Obviously, the actual location of employment for the project direct employees will vary. This will affect residency patterns and the location of a limited portion of the indirect employment impacts. The primary shifts in the indirect employment impacts will occur between Spearfish assuming development at the Raspberry Gulch site and Sturgis if project development is located at the Two Bit Creek site. The yellow Creek site is midway between the two towns and would result in some indirect employment gains in both towns.

Personal Income

The indirect impacts on local personal income associated with a gold heap leach facility would parallel the impacts on employment. Project direct wages and salaries of \$875,000 would be paid during the initial year of construction, increasing to \$1.75 million the second year. Annual direct payroll during the operating life of the project would be \$2.5 million. These estimates are based on average earnings of \$25,000 per full-time employee, reflecting current average payroll at the Wharf Resources Annie Creek project (Mountain International Inc, 1985).

As is true in employment and population, there will be an indirect impact on personal income resulting from the local purchases of goods and services by the mine and employee households. The average multiplier for personal income is estimated at 1.6, versus the 2.0 multi-

plier used for employment. The lower multiplier reflects the lower average earnings in other industries, such as retail trade, compared to mining and the expectation that some of the household consumer purchases will be made outside the local economy, especially in Rapid City, the regional trade center. Therefore, the combined annual impact on personal income is estimated at \$1.4 million and \$2.75 million during the 2 years of construction and \$4 million annually over the operating life of the mine. Following the end of operations, the local payroll impact during reclamation will be \$200,000 more than premining conditions.

The effects of higher personal incomes will be distributed primarily according to residency patterns and the distribution purchases by the mine. Based on the experience of the Wharf Resources operation, 40 to 50 percent of the purchases are made in the Lead-Deadwood area and 50 to 60 percent of purchases are nonlocal, primarily in Rapid City. Measured against total wage and salary earnings of \$135.7 million and total personal income of \$199.4 million in Lawrence County in 1984, these impacts would be beneficial but not significant on a county basis. On a local basis, they would provide a welcome infusion of additional income into the Lead-Deadwood economy which has experienced a prolonged period of decline. This would be a moderately beneficial, but not significant, impact. The magnitude, incidence, and significance of the impacts would not vary with the alternative mine sites except as the residency pattern varies.

Economic Base

The potential exists for both beneficial and adverse impacts on the local economic base. The initial impacts would be positive in that a new infusion of jobs and payroll would occur into a local economy which has experienced lackluster performance over the past several years. Retail and personal service establishments located in Lead and Deadwood would benefit particularly from the economic growth. The anticipated operations procedure of maintaining year-round employment would be a positive influence on an economy that currently experiences heavy seasonal fluctuations in employment.

Conversely, there are several downside risks involved. First, the project would not contribute to economic diversification. Rather, it would perpetuate the reliance on the mining industry. Although the local mining industry has been relatively stable, other local economies such as Butte, Montana and Leadville, Colorado have experienced substantial economic swings due to the heavy reliance on the mining industry.

A second potential adverse impact could result from conflicts with recreation facilities. The Raspberry Gulch site is close to two developed downhill ski areas. Because of mineral ownership patterns underlying the areas, there is a potential for possible interference with the recreation use of these areas. Even without direct interference, noise and changes in visual quality associated with heap leach operations may have indirect impacts on the quality of recreation experience and possibly the amount of recreation occurring. Changes in visual quality might also affect general tourism and second home vacationers, if the operations are highly visible from the major highway corridors. The likelihood of such impacts occurring is uncertain, and with respect to visual awareness from highways, impacts are very site-specific and somewhat under the control of the operator. However, if they were to occur, they could adversely impact the region's recreation and tourism industry. The likely component of the tourism market affected would be the regional resident who comes to the area as a destination-type visitor or summer home occupant, not the tourists who visit the area as part of a vacation or multi-destination itinerary. The relative economic impacts associated with the former would be less than an adverse impact on the latter category of tourism.

Considering both the potential beneficial and adverse impacts on the local economic base, the development and operation of a heap leach facility are considered moderately beneficial over the life of the project. Impacts would not be expected to vary among site alternatives.

Population Trends

The population of Lawrence County grew 5.1 percent during the 1970's, from 17,453 in 1970 to 18,339 in 1980. During this same period Deadwood and Lead lost population, largely because of a decline in the mining industry. It appears likely, based on current economic conditions, that in the absence of major new economic activity or a dramatic resurgence in mining brought about by \$20 to \$25 per gram (\$600 to \$800 per troy ounce) gold prices, Lawrence County could be expected to continue to grow at a rate close to historical levels. At this rate it would reach a population of about 19,600 in 1990 and 20,400 in the year 2000. However, without additional new local economic activity, population growth is not likely to occur in the Lead-Deadwood area. Economic adjustments which have occurred there suggest a future stabilization or slight decline in the population level.

As discussed earlier, new jobs generated by a new heap leach gold mining operation would primarily go to existing residents of Lawrence County. The major impact of the new jobs would be the stabilization of the declining population in the Lead-Deadwood area. In addition, it is anticipated that there will be a population gain to the region of 90 people resulting from in-migration to fill jobs not filled by local residents. Fifty percent, or 45 people in 17 households, would be expected to settle in the Lead-Deadwood area with the remainder going to Spearfish, other areas of Lawrence County and, possibly, Sturgis.

Under all mine location alternatives the impacts on Lead and Deadwood would be the same because both communities are located in the center of the mining district. However, the distribution of the remaining in-migrating population would be expected to vary among the three site alternatives. A mine operation at the Raspberry Gulch site would make a residential location in Spearfish relatively more attractive while a mine at the Two Bit Creek site would have good access to Sturgis via U.S. Highway 14 ALT. If a mine was located at the Yellow Creek site, neither Spearfish nor Sturgis would have a clear advantage

as a residential location and the population not locating in Deadwood or Lead would likely be more dispersed between Spearfish, unincorporated Lawrence County and Sturgis.

Housing

The development and operation of a gold heap leach facility in the Lead-Deadwood area would be associated with total job creation of 200 full- and part-time positions, an associated population of 450 persons, and a total of 167 households. However, a majority of these households are expected to be current residents of the region who would not relocate. The effect of the increase in local employment opportunities and indirect effects on the retail and services industries will be primarily a slowing or stemming of the rate of population loss. The net impact is projected at fewer than 20 new households requiring housing during the operation period. The impacts during the construction and reclamation periods would be even smaller.

Even though a large portion of the existing housing stock in Lead and Deadwood is vacant, it tends to be in disrepair and unappealing to the current market preferences. Recently, the lack of housing was identified as one of the factors contributing to the decline in local population as households relocate to Spearfish and/or Sturgis. However, both Lead and Deadwood have recently annexed property suitable for residential development and are extending water and sewer services to these areas. Also, several rural subdivisions currently exist or are under development in the area. These include several located to the east and south of Deer Mountain ski area; north of Raspberry Gulch in the Dutch Flats area; south on U.S. Highway 385 along Strawberry Ridge towards the western access route to the Galena and Anchor Hill area; and along the Peedee Gulch road providing access to the Anchor Hill/Dome Mountain area. Hence, the impact of the mine will be to spawn some additional residential construction in the area. This impact will be primarily beneficial although insignificant.

The overall impacts on housing within the Lead-Deadwood area would not be expected to vary greatly with the location of the project, although the residency pattern of the work force among other communities and the amount of development in rural parts of the county may shift with the project site. Development of mining operations in Raspberry Gulch would increase the overall share of project employment commuting to the Spearfish area and the amount of rural residential development occurring south of Lead along U.S. Highway 85. Mine development in the Yellow Creek site would result in a slightly higher portion of employment residing in the Lead-Deadwood area and commuting of employees to both the Sturgis and Spearfish areas. A shift in residency patterns resulting in a higher concentration of residency and, consequently, additional housing need in the Deadwood and Sturgis areas would be expected if development occurs at the Two Bit Creek site.

Development occurring at either Raspberry Gulch or Two Bit Creek would result in mining activity within a 1- to 2-mile radius of existing concentrations of second home and year-round residential development with the likely highway access routes passing by these areas of development. This proximity increases opportunities for conflicts and for noise and esthetic impacts. The Yellow Creek site is more removed from areas of existing residential development and its access roads already carry considerable truck traffic associated with the operations of the public dump sites located in the Yellow Creek area. On a relative basis, Raspberry Creek possesses the highest likelihood of adverse impact. The impacts associated with Two Bit Creek are lower and Yellow Creek site has the least likelihood of adverse impacts on existing residential development.

Community Services and Infrastructures

Schools. The Lead-Deadwood School District No. 40-1 serves Lead, Deadwood, and the surrounding unincorporated area. Since consolidation of the district in 1972 there has been a steady decline in enrollment and the district facilities now being utilized could accommodate up to

200 additional students without significant impact on district operations. Depending upon the number of students added, additional teaching staff could, of course, be required. Based on added population to the area from the mining operation, it is anticipated that between 10 and 20 students would be added to the school district enrollment. This increase could be accommodated with a minimal or negligible increase in staff and facilities. This impact would not vary by mine site alternative. Increased assessed valuation resulting from mine development at any of the three locations would be within the school district boundaries.

Law Enforcement and Fire Protection. Law enforcement and fire protection is provided locally by a series of agencies working together in a cooperative framework which maximizes the level of protection afforded given limited human and physical resources. While each agency has its own primary jurisdiction and responsibilities, there are a number of formal and informal arrangements in place to supplement the individual capacities of any single agency. For example, the Deadwood Fire Department has an aerial/ladder fire truck which can be used to suppress fires in multistory structures. The Lead Fire Department does not have such equipment, but can call upon the Deadwood Fire Department if needed under a mutual assistance pact.

At present, the local fire protection services are adequate and are in the process of being upgraded. Therefore, there would be no appreciable impacts associated with the project.

The primary law enforcement agency serving the region is the Lawrence County Sheriff's Department. In addition to patrol and investigation duties throughout the county, the sheriff's department handles communication and dispatch services for all law enforcement and emergency services throughout the county as well as detention facilities. Additional staffing is desired at the current time, but the needs are not critical and the quality of law enforcement afforded is not affected. Additional law enforcement assistance in the area is provided by the South Dakota Highway Patrol offices stationed in Deadwood.

Both of the municipal police departments in the area have existing needs. The Deadwood Police Department needs additional staff, updated patrol vehicles, and additional office space. The Lead Police Department is in need of improved office space.

The limited population associated with a heap leach facility would not generate significant impacts on local law enforcement agencies. Some additional traffic enforcement and motor vehicle accident investigations will occur as traffic volumes increase. The incidence of these impacts may shift depending on the location of the mine site, as different access routes involve various combinations of Federal, State and local roads. However, the significance of impacts would be unchanged.

Medical Care. As indicated previously, a new mine would slightly increase population levels, by less than 50 persons, in the Lead-Deadwood area. Based on the current population of about 6,000 in these two municipalities, and the current occupancy level of 40 percent at the Northern Hills General Hospital, there would not be any demand placed on local health care facilities and services which could not be met. In fact, the stabilization and slight increase in population which would occur might help to assure that the current level of health care services would continue to be provided in the Lead-Deadwood area.

The impact on health care facilities in other communities such as Spearfish and Sturgis would be minimal as even fewer individuals would be involved and the facilities available in these larger communities are generally more extensive. The impacts would follow the same patterns as population and would vary slightly among the three sites, but would not be expected to strain the capacity of health care delivery systems.

Solid Waste. Regular residential and commercial garbage and trash collection in the city of Lead is handled by a private contractor. Solid wastes are hauled to sanitary landfills near Belle Fourche or Sturgis. Deadwood garbage collection is handled by the municipality and the waste is hauled to Belle Fourche or Sturgis. Deadwood is

currently considering shifting its garbage collection to a private contractor. The facility at Belle Fourche, which is currently used by the major contractor in the area, has an estimated 50-year life. The small additional population moving into the area as a result of the mine operation would not be expected to produce sufficient additional waste to impact the lifespan of that facility (K. Petersen, Belle Fourche Sanitary Landfill, personal communication, 1986).

The only other solid waste facilities in the area are a series of separate dump pits south of Lead operated by Lead-Deadwood, the Homestake Mining Company, and the Black Hills Power and Light Company. Only the Lead-Deadwood facility would potentially be impacted by the mine development. This facility is open to the public on a fee basis but dumping is limited to metals and burnables. It receives limited use by the cities, including Lead's annual spring trash pickup. The facility has an estimated remaining life of 13 years but this may be extended by expansion and improved management techniques such as compaction and selling off salvageable metals. It is not expected that the population growth attributable to the mine operation would affect the lifespan of this facility.

No hazardous materials resulting from the mine operation would be disposed at the area dump or sanitary landfill facilities. Hazardous materials would be handled by the mine operators or by private contractors as is the practice at current mine operations.

The impact of mine development on local solid waste facilities and operations would be negligible. The major share of this activity is handled by private contractors and the additional volume would be insignificant relative to overall solid waste now produced in the area. The level or nature of the impact would not vary by the mine location alternative.

Water and Wastewater. The domestic water supply for the communities of Lead and Deadwood is obtained from water resources developed by the Homestake Mining Company. Total capacity of the system is 30,800 cubic meters (8.15 million gallons) per day. Peak demand is currently

28,000 cubic meters (7.4 million gallons) per day. The water demand generated by the 17 additional families expected to move into Lead and Deadwood as a result of mine development would not be likely to exceed 23 cubic meters (6,000 gallons) per day and could easily be accommodated by the existing water system. Both communities also have adequate storage and delivery systems and are able to provide sufficient volume and pressure for firefighting purposes. No impact is foreseen on this capability.

Sanitary sewer and wastewater treatment for a population of 7,000 to 8,000 people in Lead, Deadwood, Central City; and a small unincorporated area is provided by the Lead-Deadwood Sanitary District No. 1. The district operates an activated sludge treatment facility built in 1979 with a capacity of 8,820 cubic meters (2.33 million gallons) per day. This capacity is seldom exceeded except during periods of heavy rain, when Lead's storm runoff flows into the sanitary treatment system resulting in total flows of as much as 30,000 cubic meters (7 million gallons) per day. During periods when storm runoff is not a problem, the system operates at a peak demand of about 8,700 cubic meters (2.3 million gallons) per day, which is near capacity. Therefore, any major additions to the population base in the district could require that wastewater treatment facilities be expanded. The 17 families added to the area by mine development would contribute up to 17 cubic meters (4,500 gallons) per day to the wastewater flow. Although this additional flow would contribute to a potential need for expanded facilities it is unlikely that this population increment would by itself require Sanitary District No. 1 to increase its wastewater treatment capacity.

County Roads. Heap leach gold mining operations would involve onsite processing of the ore. Therefore, frequent heavy equipment travel over roads to and from the site would be limited to the construction phase of the mine and would largely depend on the need for materials from offsite sources. After the construction of mine facilities was completed and actual mine operations were underway, transportation impacts would consist primarily of mine employees commuting

to and from the facility. Some heavy truck traffic associated with the delivery of fuel and chemicals would occur. However, the volume of such traffic is expected to be low.

Impacts of the project on roads in the Lead-Deadwood area would primarily affect the county road and bridge department, but would vary depending upon where development took place. In some instances, roads have recently been upgraded and would require little additional attention. In other cases, roads are currently identified as needing improvement and this need would become more immediate if mining activity were to occur. Other roads are adequate for current use but would require improvements to handle the increased volume and intensity of use caused by a mine operation. Virtually all potential mine sites would impact some county maintained roads and road segments. In addition to potential improvements, increased maintenance and snow clearing efforts would also be required as a result of the operations. As has occurred in the past, it is anticipated that necessary road improvements would be a cooperative venture among the county, the U.S. Forest Service, the Bureau of Land Management and the mining company. As necessary, cooperative agreements could be negotiated as part of the extractive industry special use permitting process being developed by Lawrence County. The greatest impact on county roads would result if development occurred at the Yellow Creek site because this area is primarily served by county level roads. The Raspberry Gulch site and the Two Bit Creek site are close to major State-maintained highways which would bear most of the traffic load if development occurred in those areas.

General Government. As a result of declining populations in Lead and Deadwood there have been cutbacks in the overall level of local government administrative staff in Lawrence County over the past several years. At the same time, older buildings housing government offices have deteriorated to the point where they can no longer be used or are in need of renovation. As a result, the municipalities of Lead and Deadwood and the county are all developing plans to remedy the space shortages for governmental administration. Mine development

could place additional demands on local governments requiring some additional staff and could contribute to the existing office space shortage. However, the additional needs attributable to mine development would be minor relative to existing needs. This impact is not considered to be significant and would not be expected to vary by mine site alternative.

Fiscal Resources

A gold heap leach project would have both beneficial and adverse impacts on local fiscal resources. Beneficial impacts would accrue in the form of additional property taxes to the county and school district and additional sales tax receipts to the municipal budgets of Lead and Deadwood. Based on information supplied by Wharf Resources, the property tax payments to the county will total less than \$20,000 annually due to the relatively low capital investment associated with heap leach operations. Increased annual sales tax receipts to all local communities would be between \$10,000 and \$20,000. Sales, severance, and corporate net profits taxes would also accrue to the State. Indirect tax revenues would accrue to these same entities based on property tax collections on residential and commercial development and sales taxes on household expenditures. There is no personal income tax in South Dakota.

There would also be negative fiscal impacts of mine development. These impacts would result from the need to provide services to a larger service-area population and commercial/industrial base. The Lawrence County Highway, Planning, and Sheriff's Departments would experience the greatest impacts, especially the first two of these agencies. The highway department would experience increased needs for road maintenance and possibly snowplowing operations to provide year-round access.

The increased demands on the planning department will be in the form of increased staff effort associated with the issuance of a conditional use permit and monitoring of project operations with respect to that permit. Because the department presently has only a

single full-time professional and half-time secretarial assistance to cover the entire county, any increase in the workload would constitute an adverse impact.

The mine would increase demands on the sheriff's department for general law enforcement activities, especially traffic enforcement and accident investigation. These impacts would translate into needs for additional staff and expenditures. However, in light of the substantial volumes of resident and tourist traffic presently occurring in the area and the extensive highway network currently patrolled by the department, the incremental impacts would be minimal.

Additional demands for public services would be generated by the project-related household and population impacts. All public service agencies would be affected. However, many of these services, such as the school system and hospital, have excess capacity available to accommodate the growth. Other public service providers such as the Lead-Deadwood Sanitary District No. 1 already have existing needs. The limited additional growth will increase the needs, but not be solely responsible for any system reaching a threshold that requires expansion of capacity and major capital investment. These agencies will receive limited additional revenues from their traditional revenue sources, be they fees for services rendered or property taxes.

A lack of quantitative projections of project-related impacts on public revenues and expenditures by jurisdiction and agency prevents a quantitative determination of net fiscal impacts. However, the primary revenue flows will accrue to the State, with successively lower revenues accruing to the county, municipalities, and service providers. The increased demands for services will, however, be widely distributed across numerous separate service providers. The overall net impact will be an insignificant adverse impact. The magnitude, incidence, and significance of impacts would not vary by the location of the mine among the alternative sites.

Recreation Resources

The Black Hills National Forest is a major recreation area of the State and provides opportunities for camping, boating, hiking, hunting, fishing, downhill and cross-country skiing, and snowmobiling. Developed recreation sites in the immediate Lead-Deadwood area include the Hanna Campground and the Deer Mountain and Terry Peak ski areas. Most of the dispersed recreation activity such as stream fishing and hiking occurs on public lands managed by the U.S. Forest Service (Figure 21).

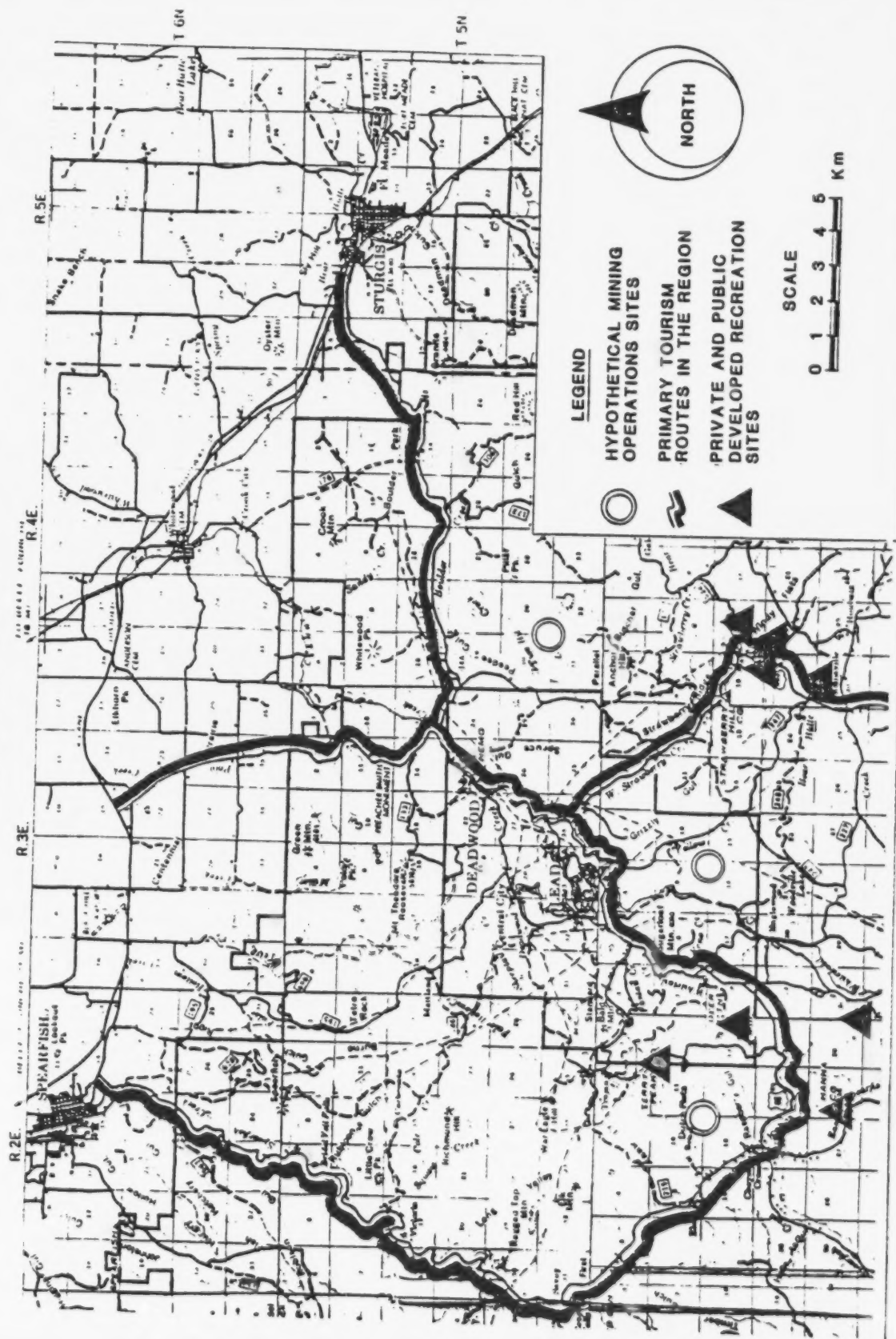
The impact of a gold heap-leach facility on recreation can be evaluated in terms of the amount of recreation activity displaced by mining operations and the potential for indirect impacts on the overall recreation experience such as noise, traffic or visual/esthetic changes associated with the project. With respect to the potential impacts on recreation from heap leaching operations in the northern Black Hills, they are best considered on a site-specific basis.

Across all of the alternative sites, those impacts on recreation resulting from direct loss or interference with a developed recreation facility would be expected to be long-term, as would most of the indirect impacts on the recreation experience associated with esthetic changes. Indirect impacts associated with project operations, such as noise and traffic, would continue over the life of the project.

Raspberry Gulch. The potential for significant adverse impacts among the alternative sites is greatest at this location. It is located southwest of the only two developed downhill ski areas in the entire Black Hills area. The combined annual activity of these two areas is between 100,000 and 120,000 skiing-visits.

As described, the mining area would not involve direct interference with the ski area operations through use of any of the lands involved. Adverse effects on the recreation experience for skiers could potentially occur as a result of equipment noise, blasting of the ore deposits, or affects on esthetics. The latter would occur as a result of the contrasts between the existing heavily forested hills and the exposed soils and rock in the mine and work pits, as well as the

FIGURE 21
TOURISM ROUTES AND
RECREATION SITES



well-defined linear outlines of the heap piles. Because the lifts and runs for the ski areas face an arc of 210 degrees from due west to southeast, the potential for impacts is somewhat lower at the Raspberry Gulch site than would occur if the relative location of the mine were to be in any of the other three geographic quadrants surrounding the ski areas. For example, the existing heap pile for the Wharf Resources project is visible from the top of the Terry Peak chair lift.

The potential for other direct and indirect impacts on dispersed recreation are also quite high at this site. It is located just south of a vacation home development on Dutch Flats and immediately north of several clusters of recreation cabins located along Spearfish Creek near Cheyenne Crossing. Spearfish Creek is rated as having the best fishing in the area, although a stocking program is presently used to maintain the fish population and fishing quality in Spearfish Creek. While the total amount of recreation and leisure activity occurring in the area is not available, and no adverse effect on aquatic life is expected, the potential exists for adverse effects from mine development on the quality of the fishing experience.

With respect to impacts on esthetic qualities for tourists in the area, the most likely vantage point would be from Cheyenne Crossing to the south. However, Cheyenne Crossing is located at the confluence of the east and west forks of Spearfish Creek and is characterized by narrow canyons with limited fields of visibility. Therefore, these impacts would be limited. Overall, however, locating gold heap leach operations at the Raspberry Gulch site could result in potentially significant adverse impacts on recreation.

Yellow Creek. The potential for recreation impacts is limited at this site. The site is located in an area that receives little current recreation use, is close to a number of public dump sites, has heavy truck traffic already occurring, has no developed recreation sites, does not currently have and is not expected to support substantial permanent or seasonal residential development, and is not highly visible from major tourism routes or developed recreation sites.

Therefore, there will be essentially no impact on recreation from mine development at the Yellow Creek site.

Two Bit Creek. Potential recreation impacts in this area would only affect dispersed recreation as there are no developed recreation sites in the area. The land is a combination of private mining claims and public lands managed by the U.S. Forest Service. According to the forest service's local recreation planner, the area does not receive significant use, primarily because it is not particularly scenic relative to other nearby areas and the fish and wildlife populations are limited.

The primary activities currently occurring in the area are fishing, hunting, hiking and 4-wheel driving on the old logging and mining roads. The site comprises a portion of an elk habitat area located southeast of Deadwood. However, because the elk herd is small, 30 to 50 animals, no elk hunting is currently allowed in the area.

The Two Bit Creek site is located within a 3-kilometer (2-mile) radius of both seasonal and permanent residential developments. Thus, additional private recreation may be occurring in the area. Overall, mine development at this site could result in limited adverse impacts on recreation, but they would not be significant.

Lifestyles and Attitudes

Development of heap-leach mining facilities in the Lead-Deadwood area would reinforce historical-traditional lifestyles in the area. Since the area's initial settlement by prospectors during the Gold Rush of 1874 to 1876, mining has been the predominant force behind the county's economy. In spite of recent declines in both the nation's and the local area's mining industries, mining still accounts for 18 percent of total county employment and nearly 40 percent of total local wage and salary earnings.

The example mine would provide additional employment opportunities for existing unemployed members of the labor force and future entrants into the labor force who might otherwise leave the area. A small influx of new residents is expected to fill key management and technical positions and to fill any voids not satisfied by the local labor force. These new residents would share a lifestyle similar to the existing permanent residents of the area.

To the extent that a gold heap leach facility creates conflicts of lifestyle, it is likely to affect a limited number of seasonal summer home residents, owners/residents of permanent year-round homes, and the operators of the two ski areas. All of these developments are located in close proximity to the areas of active exploration and development or along the primary access routes to those same areas. In many instances, the owners of the residences or recreation facilities do not own the mineral rights underlying the property, or in some cases, do not even own the surface rights, but occupy the land under property lease arrangements. In either case, these owners knowingly entered into an arrangement where the potential for mineral extraction has long been established. The fact that these rights have not been exercised previously must, to a great extent, be viewed as a windfall to those residents, not as a basis for prohibiting mining or for seeking undue compensation. In instances where permanent or seasonal home property owners own both mineral and surface rights, a legitimate lifestyle conflict may arise between the rights of all parties to have access and use of their properties in whatever manner they choose, as long as it complies with local land use ordinances and does not endanger the public health, safety, and welfare.

In any case, the numbers of individuals affected is small in comparison to the economic benefits to the community as a whole. Furthermore, there are means available to minimize the potential conflicts associated with mining activity occurring in close proximity

to other existing land uses. These could include a negotiated agreement between property owners specifying reduced operating speeds for company-owned and employee vehicles in the proximity of residences to reduce noise and dust.

Overall, the issue of lifestyle conflicts reduces itself to weighing economic livelihood benefits accruing to numerous households and the community-at-large against the rights of individual property owners. Although there are definite negative impacts associated with mine development, the strong historical role of mining in the community, the well established record of mineral rights ownership, and the economic benefits associated with the project would effectively outweigh the adverse impacts resulting in an overall net beneficial impact on lifestyle.

Impacts on lifestyle will definitely vary on a site-specific basis. Because of the existing level of residential and recreational development around Raspberry Gulch, the general conclusion of net beneficial impacts would change to an insignificant adverse impact. The general assessment of beneficial impacts would apply to both the Yellow Creek and Two Bit Creek sites.

Cumulative Impacts

If two or more new mining operations are developed in the area, cumulative impacts could not be estimated by simply multiplying the impacts described here for one mine by the total number of new mine operations. The impacts from two or more mine operations developing simultaneously could be much different than additive analyses would indicate. For example, the driving force of most socioeconomic impacts is employment, both at the mine and resulting as a secondary impact of the mine operation. For a single mine operation, 80 percent of the new jobs could probably be filled by Lawrence County residents. This would result in a relatively small in-migration to the county and the Lead-Deadwood area. However, for employment generated by a second or third new mine operation simultaneously opening in the county, the percent of jobs which could be filled by local residents would decline.

This would result in more in-migration and proportionately greater impacts on everything from schools to wastewater treatment. Thus, the impact from a number of heap leach gold processing operations in Lawrence County would be very different from the impacts portrayed in this analysis, and further evaluation would be required to assess the cumulative impacts of multiple new operations in the county.

SUMMARY OF PROJECTED IMPACTS

The potential effects of an open pit mine and cyanide leaching operation in any of the three drainages selected for study are summarized in Table 40. All of these impacts are based on the hypothetical mine described in Chapter 4, including the example cyanide spill and leak situations. Except for socioeconomic impacts, the significance of the impacts did not depend on the drainage in which the operation was located. The table lists resources affected by any cyanide leaching facility in the Black Hills. The expected duration and significance of effects are assessed for specific individual activities which constitute the operation. Although this evaluation is specific to the sites and hypothetical facility discussed in preceding sections, the table can be modified to illustrate the projected impacts from actual proposed projects which may have their own unique effects.

The environmental and socioeconomic effects of an open pit mine and cyanide heap leach operation vary, depending on the location of the facility, the areal extent of disturbance, and the configuration of the mine facilities. The impacts to soils, vegetation, and wildlife are primarily a function of the location of the project, the size of the area disturbed, and the amount and success of post-mining reclamation. The impacts to surface and ground water and to aquatic life are a function of the distance of the operation from streams or regional aquifers. The proximity to critical wildlife habitat is also an important factor in influencing impacts to wildlife species. Socioeconomic effects depend on the distance of the operation from developed recreation areas and population centers. Site-specific baseline investigations and impact assessment are necessary to determine more

TABLE 40
SUMMARY OF IMPACTS FOR CYANIDE
HEAP LEACHING IN THE BLACK HILLS
(EFFECT/DURATION/SIGNIFICANCE)

	Mine Pit	Waste Rock Disposal	Roads	Crushing Facility	Heap-Leach Process Area	Accidental Leaks	Accidental Spills
Physical Resources							
Ground water	-/P/I	0	0	0	-/P/I	-/L/I→S	-/C/I
Surface water	-/C/I→M	-/L/I→M	-/C/I	-/P/I	-/P/I	-/C/I	-/C/I→S
Soils	-/L/I	-/P/I	-/P/I	-/P/I	-/P/I	-/C/I	-/C/I
Biological Resources							
Vegetation	-/L/I→M	-/P/I→M	-/P/I→M	-/P/I→M	-/P/I→M	0	-/C/I
Wildlife	-/L/I→S	-/P/I→S	-/P/I→S	-/P/I→S	-/P/I→S	0	-/C/I→M
Aquatic Life	-/C/I→M	-/L/I→M	-/C/I	-/P/I	-/P/I	-/C/I	-/C/I→S
Socioeconomic Resources							
Population (Growth)	+/P/I	+/P/I	+/P/I	+/P/I	+/P/I	0	0
Services/Utilities	-/P/I	-/P/I	-/P/I	-/P/M	-/P/I	0	0
Employment	+/P/M	+/P/M	-/P/M	+/P/M	+/P/M	0	0
Recreation	-/L/M→S	-/L/M→S	-/L/M→S	-/L/M→S	-/L/M→S	0	-/C/M→S
Housing	+/L/I	+/L/I	+/L/I	+/L/I	+/L/I	0	0

Effect
+ = positive effect
- = negative effect
0 = no change

Duration
L = Long-term (12 years to beyond project life)
P = Project Life (3 - 12 years)
C = Short-term (construction phase or 1-2 years)

Significance S = Significant
M = Moderate
I = Insignificant

→ = Indicates potential range of impact significance which would depend on specific characteristics and location of mine development.

accurately the significance of potential impacts. Therefore, where site-specific information is not available for the hypothetical mine example, a range of anticipated significance is provided in Table 40.

Mass-wasting of the disturbed areas, particularly at the mine pit, can be prevented by adequate slope stabilization techniques. Other impacts to geological resources are not anticipated.

Effects on ground water quality may occur in conjunction with pumping drawdown from wells used to provide water to the mining and ore processing operations. If the presence of shallow aquifers requires mine pit dewatering, some lowering of the water table and possible changes in ground water quality may also occur. These impacts, although negative, would be insignificant over the life of the project. No long-term ground water quality changes are anticipated from general mining operations since sulfide ore would not be disturbed. An accidental leak of process solution could have potentially significant, long-term impacts to ground water quality if the water table (such as an alluvial aquifer) was near the surface. If the depth to water is greater, as in the case with the hypothetical mine, the impact on ground water quality may be minimal. Impacts to ground water quality from a process pond overflow could be insignificant because of attenuation of cyanide and limited infiltration.

Impacts to surface water resources caused by increased sedimentation from the general mine operations would occur primarily during the construction phase. These impacts could vary from insignificant to moderate, depending on the proximity to a major stream and on the sediment control structures provided. Runoff from mine facilities and roads over the life of the project would have minimal effect on water quality if runoff control structures are installed and maintained. A moderate increase in sedimentation from erosion of the waste rock piles could continue beyond the project life if the pile is located in a drainage. A leak in the pond as described in the example is expected to have a minimal or even undetectable effect on surface water quality. However, if the distance between a spill and the ground water discharge point was small, the impact to the receiving stream could be moderate.

A process solution spill would have a short-term effect ranging from significant on a stream adjacent to the facility to insignificant in downstream reaches because of dilution and attenuation.

Soils would be removed and compacted during construction and operation of the mine facility. For some areas at the site, the effects would be temporary and stockpiled soil would be redistributed during reclamation. However, in the case of the mine pit, which is not scheduled for reclamation at the end of the project, this effect would extend beyond the life of the project. Accidental releases of cyanide solutions would have short-term, insignificant impacts on soils because potentially toxic solution constituents would be transformed to harmless or inert forms.

Vegetation resources would be removed or disturbed during the construction phase. The resource would be restored in some areas of the site during reclamation. However, in other areas, such as the mine pit, reclamation would not occur for some time, causing a long-term vegetation loss in these areas. The significance of these losses to vegetation depends on the specific types of communities disturbed. A spill would have short-term but insignificant effects on the plant community because of cyanide attenuation and dilution and the low inherent toxicity of cyanide to plants. Leaks are not expected to affect vegetation resources.

Wildlife would primarily be affected by habitat losses and degradation and increases in wildlife-human confrontations. The significance of the effects depends on the wildlife present under preproject conditions, the availability outside of the disturbed area of the habitat lost or degraded, the extent of the habitat loss or degradation, and the intensity of the human encounters. Disturbance of winter habitat or other specialized areas could have a significant effect on wildlife populations critically dependent on such habitats. Most effects would continue through the life of the project until habitat was restored during reclamation. Some long-term impacts would be experienced in areas that are not immediately revegetated, such as the mine pit. Only minor impacts from road kills and poaching would be

expected from the mining operation. Generally, no impacts to wildlife are expected from a process solution leak because the leaked solutions would not be available to wildlife species. If the leaked solutions were eventually discharged to surface waters, toxic substances would be sufficiently diluted or attenuated so that wildlife poisonings would not occur. Some direct mortality could occur during a pond spill if animals were to drink the process solution before dilution or attenuation of the toxic components could occur. This type of direct mortality could also occur if animals were to gain access to the processing facility and drink process water. These impacts would be insignificant to moderate, depending on the numbers and kinds of animals near the site and the concentration of the solution components.

Impacts to aquatic life could result from increased erosion and contamination of surface waters. Some increased sedimentation could occur, particularly during construction. These impacts would be insignificant if adequate sediment control structures are used. In the waste rock disposal area, effects from erosion and sedimentation could be moderate and long-term if the pile is placed in a drainage. Impacts resulting from a process solution leak would be insignificant. Impacts from a pond spill could be significant in the first stream areas encountered. In these reaches, cyanide and metal concentrations could exceed acute toxicity levels. Most impacts, however, would be short-term because of rapid cyanide attenuation and dilution. Metals, although diluted to below toxic levels, would probably remain in river sediments for some time.

Many of the socioeconomic impacts of a heap leach operation would be similar regardless of the location of the mining operation. There would be moderate beneficial effects on employment, income, and the economic base during the life of the project. This would be accompanied by positive but insignificant impacts in population and permanent housing in nearby towns. The expected additions to the housing stock would be a long-term benefit continuing past the life of the mine. There would be an insignificant positive impact on schools, no impact on fire protection or solid waste disposal, and an insignificant

negative impact on law enforcement, water and sewer, and county roads. The need for additional services is expected to result in a negative but insignificant impact on local government budgets. Local governments would bear almost all of the additional costs associated with required public services whereas public revenues generated by the mining operation would be shared by the State, the county, and cities. These revenues would generally be spread over a broader geographic area than would the demands for services.

Site-specific characteristics would affect the significance of impacts to recreation and seasonal housing. Impacts could be more severe at the Raspberry Gulch site because of its proximity to recreational areas. At the Two Bit Creek site, the impacts would be less severe with no impact on developed recreation, a negative but insignificant impact on dispersed recreation, and adverse impacts ranging from insignificant to moderate on seasonal housing. There would be virtually no impact on either dispersed or developed recreation at the Yellow Creek site and an insignificant negative impact on seasonal homes.

The impact of a heap leach operation on lifestyles in the region would also vary among sites, based on the specific location and characteristics of a mining operation. The moderate positive effects on employment opportunities, income, and the economy in general are expected to outweigh the generally insignificant negative impacts on fiscal conditions, recreation, and seasonal homes at the Two Bit Creek and Yellow Creek sites. However, the potential for long-term moderate adverse impacts on dispersed recreation and seasonal homes, and potentially severe impacts on developed recreation, could outweigh the shorter-term economic gains if development occurred at the Raspberry Gulch site.

A detailed site-specific analysis would be necessary to refine this impact analysis according to actual facility location, size, and configuration. In addition, development of more than one mine operation could result in cumulative impacts to the area. It would not be appropriate to assume that cumulative impacts could be estimated by simply multiplying the impacts described for one operation. The

impacts from two or more mine operations developing simultaneously could be quite different, particularly for resources that are affected by factors other than the actual disturbed acreage.

CHAPTER 5

OPTIONS FOR MITIGATION

A number of options are available to prevent or mitigate impacts from heap leach mining facilities. Mitigating actions are most commonly implemented to comply with Federal, State, or local regulations, but in some cases are initiated by the mining company to protect unique resources or address unusual conditions at the mine site. General activities to prevent or mitigate adverse impacts at many mine sites are discussed in this chapter. The intent of this chapter is not to present an exhaustive list of available options, but rather to illustrate measures that could be used at future heap leach mining activities. All options would not necessarily be applicable to every operation.

MITIGATION OF POTENTIAL GEOLOGIC IMPACTS

The potential for mass failures can be reduced or eliminated by proper siting and engineering. Pit wall failure can be minimized by reducing slopes, increasing the bench width, and revegetating. Impacts resulting from alterations to topography can be reduced by recontouring to blend with natural topography during reclamation.

MITIGATION OF POTENTIAL GROUND WATER IMPACTS

Impacts to ground water resources at heap leach sites may result from accidental releases of cyanide, which can introduce cyanide and dissolved metals into the ground water system, or from lowering the ground water level, either through pit dewatering or by using ground water as a source of water at the heap leach mine site. Shallow aquifers generally have a greater potential for sustaining impacts to both water quality and quantity than deeper aquifers. The following measures can be implemented to prevent or reduce impacts to ground water at heap leach sites.

- . Minimize use of ground water sources and use recycling; evaluate potential effects on surrounding ground water users.
- . Locate facilities that have the potential for leaking, such as the plant, ponds, and pads, on sites where the ground water is not near the surface where possible.
- . Construct and maintain pond and pad liners adequately to prevent leaks and install leak detection systems for pond liners to contain process solution if it has leaked.
- . Construct underdrains beneath facilities to intercept leaks before they enter the ground water.
- . Rinse and neutralize the spent ore adequately (as determined by regulations) to minimize the potential for the leaching of cyanide by precipitation and its subsequent entry into the ground water system by seepage. This measure is especially important if spent ore is removed from the pad and placed on the ground without a pad.
- . Install a network of monitoring wells to assess possible downgradient impacts to ground water.

MITIGATION OF POTENTIAL IMPACTS TO SURFACE WATER AND AQUATIC BIOTA

Cyanide heap leach operations can affect surface water and aquatic life through increased sedimentation, and degraded chemical quality. Sites located along a major stream will have a greater potential for increasing stream sediment loads through runoff and erosion than sites located at some distance from waterways. This is particularly true if certain components of the operation such as waste rock piles are placed in side drainages. There are, however, a number of structural mitigation measures that can reduce the amount of sediment entering the stream.

- . Construct culverts, water bars, sediment traps, sediment basins, rip-rap, contour interceptor ditches, and return systems for runoff control to reduce erosion from roads and disturbed areas, and route unpolluted waters around disturbed areas.
- . Minimize the extent of disturbance, revegetate as soon as feasible, and protect bare soil surfaces to reduce erosion.
- . Limit the use of heavy equipment in natural drainages and repair damage to inhibit water erosion.
- . Limit the width of haul roads to single-lane access to reduce erosion and associated sedimentation.
- . Design outslopes of ponds so that they are not readily susceptible to erosion.
- . Install vegetation buffer strips to reduce both wind and water erosion.

The effect of a spill would be more pronounced in surface water systems than in ground water systems because there would be less opportunity for cyanide attenuation. Spills occurring at greater distances from surface waters could be partially or completely detoxified by natural process such as volatilization, adsorption onto soil particles, or the actions of microorganisms or plants. The following mitigation measures may be employed to reduce impacts from leaks or spills.

- . Install pond and pad liners with leak detection systems, as discussed in ground water mitigation.
- . Avoid constructing pads or ponds immediately adjacent to drainages.
- . Treat poor quality water before discharging it to surface or subsurface water systems.

- Prevent the release of chemical solutions through ditching and berming of the leach pad, processing plant, ponds, and cyanide storage areas.
- Design an emergency spill control plan and maintain a supply of chemicals to treat spilled solution.
- Design the pond system capacity to be capable of containing significant storm events in order to reduce the likelihood of a spill or breach.
- Provide auxillary power to maintain proper pond levels during main power failures.
- Re-establish the fish community, if necessary, by appropriate measures such as stocking following accidental spills.

MITIGATION OF POTENTIAL IMPACTS TO SOILS AND VEGETATION

Surface disturbances from the mine, materials stockpiles, and ore processing facilities are the major factor affecting soils and vegetation. Surface disturbance should be minimized and sensitive or unique areas (such as wetlands, populations of rare, threatened, or endangered plant species, and riparian areas) should be avoided. In areas that must be disturbed, most mitigation measures involve either initial site work or post-disturbance reclamation and include the following.

- Minimize soil compaction to the extent possible.
- Stockpile topsoils separately from all other stockpiled materials.
- Ensure that best-management practices are utilized to protect stockpiled soils and disturbed areas from wind and water erosion through the life of the project and during reclamation.
- Test disturbed soils for necessary soil amendments prior to revegetation.

- . Slope all regraded areas to promote controlled drainage and limit erosion.
- . Use appropriate plant species mixtures to revegetate disturbed areas.

In addition, if areas are recontoured during reclamation, visual esthetics are improved. Other practices to mitigate impacts from surface disturbance include enhancing offsite vegetation types, and increasing employee awareness of forest-fire and prairie-fire prevention.

MITIGATION OF POTENTIAL IMPACTS TO WILDLIFE

Impacts to wildlife result mainly from habitat degradation and destruction, and from increased confrontation between humans and wildlife. Impacts to wildlife can be reduced by avoiding sensitive or unique areas such as elk calving grounds, winter habitat, movement corridors of big game, raptor nest sites, and riparian and wetland areas. It may be possible that alternative habitats can be enhanced to offset losses of habitat removal and degradation. Habitat losses can be minimized by reducing the size of the facilities to the extent possible, while maintaining facility effectiveness and function. Site-specific investigations to avoid locating facilities in important wildlife habitats can also reduce losses.

Confrontations between humans and wildlife result from the proximity of humans to wildlife, increased noise, and traffic. Road kills, wildlife disturbance, and poaching can be reduced through the following measures.

- . Route roads and locate mine facilities around or away from important/sensitive wildlife use areas and habitat.
- . Minimize lengths and widths of roads.
- . Arrange work schedules and use mass transit or car pools to reduce the amount of traffic.

- . Conduct operations only to during daytime hours to reduce nighttime traffic and road kills.
- . Reduce speed limits and post caution signs in heavily used game areas.
- . Minimize the number and degree of curves and hills on new roads.
- . Ban firearms on the project site.
- . Establish employee penalties for wildlife law violations.

Poisoning or contamination of wildlife are secondary project concerns. By controlling wildlife access on the site, incidents of wildlife poisoning can be decreased. Adequate fencing of processing areas and netting or flagging over ponds are examples of measures that can be taken to avoid poisoning of wildlife.

MITIGATION OF POTENTIAL SOCIOECONOMIC IMPACTS

Socioeconomic impact mitigation measures can both enhance the benefits of heap leach operations accruing to the local community and minimize adverse impacts. Most of the measures suggested here can be accomplished within a cooperative working environment between mining companies, local officials and affected residents. Such an arrangement is appropriate given the limited and frequently site-specific potential adverse impacts associated with heap leach operations.

- . Prepare and obtain county approval of a comprehensive socioeconomic impact assessment prior to the granting of a conditional use permit. This action would provide for systematic considerations of site-specific socioeconomic mitigation prior to project implementation.
- . Prepare periodic (bi-annual) reporting by the mine operator, of selected key socioeconomic information, such as employment, payroll, workforce residency, taxes, and anticipated activities and employment. These data will enable the county

to compare actual impacts to those projected by the preproject assessment and to take corrective measures if impacts are either more or less severe than anticipated.

- . Mine operations can substantially increase both traffic and road damage in the area. Therefore, mine operators could enter into cooperative agreements with affected jurisdictions to assist in road maintenance and improvement efforts. Agreements typically consist of financial assistance services in kind.
- . Make initial and recurrent purchases of materials and supplies within local communities, to the extent that such items are available at costs comparable to those from suppliers outside the area. This action would generate maximum sales tax revenues in the local economy.
- . Adopt operating policies and procedures to minimize the impacts from noise, dust, and changes in esthetics/visual quality on adjacent landowners. Examples include: establishing buffer zones between active area of operations and adjacent land uses; conducting blasting operations only between 7:30 a.m. and 5:30 p.m. Monday through Friday; regulating all vehicle speeds on public access and mine roads in the vicinity of residences or other non-industrial developed areas; and limiting offsite heavy truck and equipment operations and deliveries to daylight hours.
- . Employ natural terrain, timber stands, or other features to minimize visual or aesthetic changes from the major tourist-oriented highways and developed ski areas. Consider visual impacts and how they can be reduced in the placement and design of the mine and related facilities.
- . Avoid direct interference with developed downhill ski areas through the establishment of buffer zones between mining activities and the ski facilities.

- . If multiple heap leach operations occur in an area, additional infrastructure capacity improvements may be necessary. Cooperative assistance by mine operators could include direct monetary grants, loan guarantees, or services in kind. Priorities could be established on an annual basis by a committee representing the mining industry, local government, and local residents.

CHAPTER 6
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APPENDIX A
EXAMPLE HEAP LEACH PROJECTS

STIBNITE PROJECT - PIONEER METALS NEAR YELLOWPINE, IDAHO

The description of Stibnite is based on the literature (Josey et al. 1984 and Stotts, 1985) and a site visit. The Stibnite project is located in Valley County, central Idaho, approximately 150 kilometers (95 miles) northeast of Boise. Yellowpine, 23 kilometers (14 miles) from Stibnite, is the nearest community. Yellowpine and the project site are reached via McCall or Cascade and some 100 kilometers (80 miles) of gravel, mountain road. The mine and process facilities are at elevations ranging from 2,000 to 2,300 meters (6,500 to 7,500 feet) on U.S. National Forest land. West End Creek and Meadow Creek are tributaries of Sugar Creek, which is a tributary of the East Fork of the South Fork of the Salmon River. The Stibnite treatment facilities and offices are located in the Stibnite Valley, 5 kilometers (3 miles) from the mine itself. The site topography is typical of central Idaho, with narrow steep side canyons and rapidly flowing streams. Because of the climate, mild summers and long, cold winters, the operation is limited to about 100 working days per year.

Early history of the district dates back to 1914 when claims were staked in the Hennessy and Meadow Creek areas. The Bradley Mining Company of San Francisco acquired the claims in 1927 and began mining gold/antimony ore. Operations continued until 1938. Another open pit mine near Yellowpine began operations in 1937 on gold/antimony. Tungsten was discovered at Stibnite in 1941 and, because of the World War II effort, an active tungsten mining and processing facility was put in operation. This continued until 1952 and was the largest domestic producer of tungsten during World War II. After tungsten was exhausted in 1945, large scale mining for antimony and gold was carried out. The West End deposit now being mined by Stibnite was discovered in the early 1940's by the Bradley Mining Company. It is a disseminated low grade deposit which was not economical to mine at the time.

In 1972, a soil sampling program conducted by the U.S. Geological Survey showed anomalous geochemical gold values in West End Canyon. A Vancouver, B. C., Company, Twin River Ventures Ltd., optioned the property in 1973 and drilled two diamond drill holes. The results of these test holes were encouraging. In 1975, Canadian Superior Oil took over the lease and acquired operating control. After further exploration, development drill work, metallurgical test work, engineering and environmental studies, a decision to develop the property was made.

Construction began in July 1981 on the haul road and clearing of the mine area. One year and 9.8 million dollars later, operations began. The first ore was delivered to the crusher in July 1982. In early 1986, Pioneer Metals was formed to take over the property. The property did not operate during 1985.

Geology

The district lies along a margin of the Idaho Batholith within the Salmon River Mountains. It is underlain by a large roof pendant of meta-sedimentary rocks. Both these rock types are host to gold-bearing mineralization. The roof pendant is cut by three major, northeast trending faults and the north-south striking Meadow Creek fault. The Meadow Creek fault is traceable for almost 10 kilometers (6 miles) and dips steeply to the east with an average width of 60 meters (200 feet).

The two major Yellowpine district producing mines, the Yellowpine and the Meadow Creek Mines, are located within plutonic rocks along the Meadow Creek Fault. The mineralization is described as hydrothermal replacements in fractured zones. Apparently the earliest mineralization was gold-bearing pyrite and arsenopyrite followed by scheelite and then stibnite. Areas high in tungsten and antimony do not generally carry high gold grades. Visible gold is absent in the district.

Along the West End Fault, where the gold mineralization occurs, brecciation caused by movements along the major fault planes provided the conduit system for the hydrothermal fluids to deposit coarse calcite, iron, arsenic sulfides, and gold as fracture fillings. Sulfide mineralization lies below an oxide zone and consists primarily

of pyrite and arsenopyrite. However, this mineralization has not been explored. The ore which is cyanide leachable is in the oxidized zone. That zone is approximately 60 meters (200 feet) deep in the West End Fault Area. While there appears to be some association between hydrous iron oxides in the iron stained and fractured rocks, and residual gold, it has not been possible to directly correlate rock color and ore grade.

Exploration by Superior Mining involved 92 diamond and reverse circulation rotary drill holes. Stibnite ore reserves, are estimated to be 2,336,000 metric tons (2,575,000 short tons) of ore with an average cyanide recoverable ore grade of 2.2 grams per metric ton (0.064 troy ounces per short ton) of gold. The waste to ore ratio was indicated as 2 to 1. At the end of the 1984 season after recalculating reserves based on findings from the first two seasons of operation, reserves remaining totalled 2 million metric tons (2 million short tons) at an average, cyanide-recoverable gold grade of 2.14 grams per metric ton (0.0623 troy ounces per short ton).

Mining

Conventional open pit methods are used to mine the ore. The ore zone is on a northeast facing slope at the end of a ridge. Economic grades of gold occur in three separate ore zones. Two smaller areas at the top of the ridge were mined out in the first years of operation. The main ore zone is on the slope at a lower elevation. The ultimate pit dimensions for this main area will be about 260 meters (850 feet) wide by 370 meters (1,200 feet) long and 200 meters (660 feet) deep along the high wall side. The three mine locations total an area of about 18 hectares (44 acres).

The operating season is approximately 100 working days, from June and through October. The production rate is about 15,000 metric tons (17,000 short tons) of waste and ore per day. With a waste to ore ratio of 2 to 1, approximately 5,000 metric tons (6,000 short tons) per day of ore will be mined over the life of the mine.

Mining is performed by a contract mining company under a cost reimbursable contract. The mining contractor is supervised by the company staff, which includes a survey crew that directs the contractor's operations. Two 10-hour shifts, 5 days per week are worked. Drilling is done on a 3- by 3-meter (10- by 10-foot) pattern to depths of about 7.3 meters (24 feet) with 2 drill rigs. All drill holes are sampled as part of the ore grade control program. Ore is blasted on day shift only using ANFO at a powder factor of 0.12 kilograms per metric ton (0.25 pounds per short ton). In some areas, ripping with a dozer can be used to break the rock. Benches tend to be narrow so entry to the benches may be constricted. A hydraulic front shovel with a 5.0 cubic meters (6.5 cubic-yard) bucket is used to load ore. The waste and ore are hauled distances ranging from 2 to 8 kilometers (1 to 5 miles) using 30- and 35-metric ton (35- and 40-short ton) off-road trucks. Road grades along the haulage route, range from a 10 percent decline to an 8 percent incline.

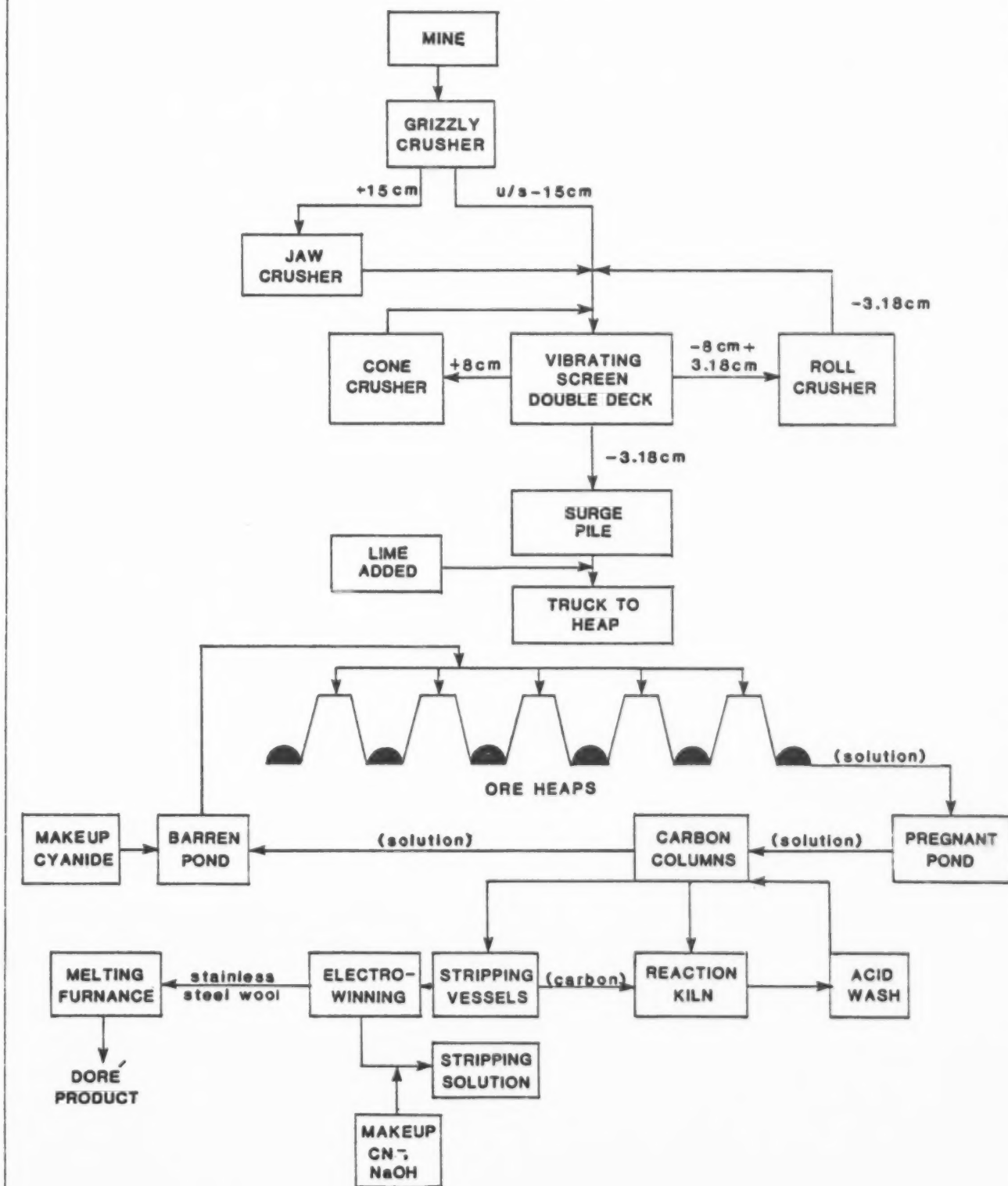
Control of ore grade is based on blast hole sample assays. After careful logging of the drill holes by geologic technicians, samples are tagged and hole sites staked for surveyors. Excavation advance is mapped on a shift-by-shift basis, based on assay results, allowing for mining control and ore and waste tonnage calculations. The tonnages are then checked against truck count tonnages. Further grade control is achieved by automatic sampling during the crushing step where the crush ore stream is sampled some 25 times per hour.

Crushing

At the crusher location, the ore is dumped from the haulage truck onto a storage pile. The ore breaks down in the mine to a relatively small size, but the moisture content of the ore normally results in few problems with blowing dust.

Ore from the stockpile is reclaimed by front end loader for introduction to the crushing system (Figure A-1). Through a series of grizzly, screens and crushers connected by conveyor belt, the ore is reduced to less than 3.18 centimeters (1.25 inches) in diameter. The

**FIGURE A-1
PIONEER METALS STIBNITE PROJECT
BLOCK FLOW DIAGRAM**



crushers include a 110- by 91-centimeter (42- by 36-inch) primary jaw crusher, a secondary 2-meter (5-foot) cone crusher, and a companion 76- by 100-centimeter (30- by 41-inch) secondary roll crusher. The reduced ore is fed to an open storage pile by conveyor where lime for pH is being added to the ore at a rate of about 0.68 kilograms (1.5 pounds) of lime per standard ton of ore. The crusher installation is portable and trailer-mounted. It operates 10 hours per day, 5 days a week with power supplied by a 400-kilowatt diesel generator.

Leaching

From the storage pile, the ore is loaded by front end loaders into 30-metric ton (30-short ton) trucks, which transport the material to the prepared leaching area. The leaching area consists of five pads which measure approximately 75- by 100-meters (250- by 350-feet) (Figure A-1). The pads are sloped 1 percent inward and toward a drain corner. They are above the surrounding grade and are well bermed along the edges.

The plant in the process area is graded so that any solution spillage and/or runoff in the plant will run toward the storage ponds.

Geotechnical investigations on the site prior to construction indicated a possible deflection in excess of 1 percent for the loaded pads. Therefore, care was taken in pad design to provide a somewhat flexible pad base.

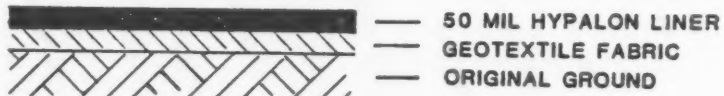
The pads were prepared by clearing, cleaning and scraping the soil surface and then placing 3 centimeters (1 inch) of less than 100 mesh tailings from one of the earlier Bradley mining operations on top. A 30-mil PVC liner was placed on top of the tailings (Figure A-2). A coarse geotextile fabric was placed over the PVC liner. A 0.3-meter (1-foot) layer of washed and open graded coarse rock was placed on the geotextile fabric. An 8-centimeter (3-inch) layer of asphalt with an asphalt seal covered the rock. The asphalt pad surface is protected during pad loading from heavy traffic by a 30- to 46-centimeter (12- to 18-inch) thick layer of crushed ore.

FIGURE A-2
TYPICAL PAD AND POND LINER AT STIBNITE MINE

PAD SECTION



POND LINER SECTION



(MODIFIED FROM STOTTS, 1985)

Ground water flow from under the pads is collected by a continuous perforated drain pipe on the downhill side of the pads. It is 1 meter (4 feet) below the PVC liner surface and runs the length of the five pads. The outlet of this perforated pipe is sampled daily and analyzed for free cyanide to detect any leaks into the ground water from the pad area. The pipe discharges outside the plant area.

Also on the downhill side of the pads, a continuous perforated drain pipe lies on top of the PVC liner. Its purpose is to collect any solution which would seep through the asphalt layer. Discharge from this pipe is monitored and flows into the pregnant storage pond. During the operating season the outlets of this drain pipe and the ground water drain pipe are sampled and analyzed daily for free cyanide.

The heap is constructed by 8-cubic meter (10-cubic yard) haul trucks dumping ore at the foot of the heap face. A loader with a 3-cubic meter (4-cubic yard) rollover bucket then pushes the ore up the face of the heap. This method is thought to reduce segregation of coarse and fine ore. Each pad holds between 27,000 and 33,000 metric tons (30,000 and 36,000 short tons) of ore, with an average pad height of about 4.3 meters (14 feet).

The entire leach cycle takes about 50 days. Ten days are used for loading the pad, 20 days for leaching and draining, 10 days for neutralizing residual cyanide and 10 days for unloading. Each of the five pad areas is at a different point in the cycle, allowing for a continuous operation.

An alkaline cyanide solution is sprayed on the level, upper surface of the heaps. The solution spray rate is about 3×10^{-6} cubic meters per second per square meter (0.005 gallons per minute per square foot) of heap area for a total flow to heap of some 0.01 to 0.02 cubic meters per second (200 to 300 gallons per minute) of solution.

Destruction or neutralization of cyanide is required by permit prior to disposal of leached ore. Therefore the cycle is operated to minimize cyanide levels at the end of the leach phase. The cyanide content of the solution at the beginning of leaching is 1,000 to 1,100 mg/l. At the end of the cycle, it will have declined to less than 250 mg/l. Cyanide consumption is about 0.10 kilograms per metric ton (0.20 pounds per short ton) of ore. The 0.75 kilograms per metric ton (1.5 pounds per short ton) of lime added during crushing are sufficient to maintain the pH level between 10 and 11 during the leaching phase. Leach solution that has percolated through the heap collects in the lower corner of the pad and is piped by gravity through the berm surrounding the pad to an 3,050 cubic meter (805,000 gallon), hypalon-lined, pregnant solution storage pond.

Processing

From the pregnant solution pond, the solution is pumped to parallel carbon column lines. Each line consists of five tanks, 1 meter (4 feet) in diameter by 2 meters (7 feet) high, each holding about 680 kilograms (1,500 pounds) of activated coconut-shell carbon. The loaded solution enters the bottom of each tank and cascades out of the top of the upper tank to the bottom of the next tank. The flow rate is 0.01 to 0.03 cubic meters per second (200 to 400 gallons per minute) per line for a plant capacity of 0.05 cubic meters per second (800 gallons per minute). After passing through the carbon column system where the gold is removed, the solution is discharged into a 1,010 cubic meter (268,000 gallon) barren solution pond. This solution normally contains less than 0.1 gram per metric ton (0.003 troy ounce per short ton) of gold. After the addition of makeup water, cyanide and lime to the barren pond, the solution is returned to the spray system for recycle to the heaps. In addition to the pregnant and barren ponds, there are two other ponds. These are for fresh water and for the neutralizing solution for the alkaline chlorination process. The fresh water and barren solution ponds are about 1,010 cubic meters (268,000 gallons) while the pregnant and chlorine solution ponds are about 3,000 cubic meters (800,000 gallons).

Pond Design

The ponds were constructed by compacting rock-free soil along the pond bottom and walls and placing a coarse geotextile fabric over the compacted material for stability and liner protection. Over this is a 50-mil, reinforced hypalon pond liner (Figure A-2). The ponds are checked for leakage at the start of each operating season by inspection of seams and by checking pond level and comparing that to loss by evaporation. Nearby monitoring wells are routinely sampled.

Cyanide Makeup

Makeup cyanide is added to the barren solution using a 1000-kilogram (3000-pound) cyanide flow bin. Cyanide is discharged into a mixing box. The mixing box is closed and cyanide is dissolved by passing leach solution through the bottom of the mixing box. Operators are protected by rubber suits, cyanide approved dust masks, face shields and rubber gloves.

Carbon Stripping

The gold-containing solution passing through the carbon column flows counter-currently to the carbon itself. This countercurrent flow is achieved by advancing the carbon about once a day by eductors from one tank to the other. Reactivated carbon enters the process when it is added to the fifth tank. Fully loaded carbon from the first tank is educted from that tank and fed to a storage bin. Carbon from each of the four succeeding tanks is eductor advanced to the tank above it. Carbon from the first tank is usually loaded to about 8,600 grams of gold and silver per metric ton of carbon (250 troy ounces per short ton). It is placed in a steel stripping vessel, 1.1 meters (3.5 feet) in diameter by 3.4 meters (11 feet) high, which is capable of holding 1,000 kilograms (3,000 pounds) of carbon. Strong caustic cyanide solution, cyanide at 10 grams per liter and caustic at 20 grams per liter, is pumped at 120° C (250° F) and 9.5×10^{-4} cubic meters per

second (15 gallons per minute) from a stainless steel holding tank through the stripping vessel. In this step, gold is stripped from the carbon and is stored to await the next step of the recovery process. The stripping operation takes about 5 hours.

The strip solution containing the gold is pumped through an electrowinning cell in which the gold is plated onto the cathode and thereby removed from solution. The electrowinning cell uses steel wool as a cathode. Electrowinning involves a current density of 500 amps and 2.5 volts. The steel wool is contained in baskets which are 0.6 by 0.6 meters (2 by 2 feet) by 10 centimeters (4 inches) thick and hold about 1.0 kilograms (2.2 pounds) of steel wool. When the cathode is loaded with 9,000 to 16,000 grams (300 to 500 troy ounces) of gold and silver, the steel wool is removed and melted in a crucible furnace along with borax and silica fluxing agents. The dore bars produced average 65 percent gold and 35 percent silver. Off gases from the furnace are scrubbed to remove objectionable metals. Only minor amounts of mercury (below allowable levels) are reported and are disposed of in the tailing area. The stripped carbon is removed from the stripping vessel and is reactivated in a rotary kiln by heating it about 66° C (150° F) for 30 minutes. Reactivation impurities, mainly calcium, are removed by washing the carbon with nitric acid. The carbon is then returned to the adsorption circuit for recycle.

Plant Area Surface Water

Because portions of Meadow Creek originally ran near the plant area, the stream was redirected so that it is no closer than 90 meters (300 feet) from the plant. Permits from both Idaho and the U. S. Army Corps of Engineers were required to alter the stream course.

Cyanide Destruction

Cyanide destruction requires 2 days for draining the pile, 6 days for neutralizing the pile with the hypochlorite solution and another 2 days for final draining of the neutralizing solution. Neutralization continues until a 24-hour average free cyanide concentration in the effluent from the pile of 0.2 mg/l is reached. The alkaline chlorine

solution is actually calcium hypochlorite, prepared as needed by adding milk of lime to the spray pipeline followed by the injection of chlorine gas into the slurry pipe venturi (Figure A-3). Chlorine consumption is 2,000 kilograms (4,000 pounds) per day and lime requirement is about 1 kilogram (2 pounds) of lime for each 0.5 kilogram (1 pound) of chlorine. The resulting solution has a equivalent chlorine concentration of 1,000 to 1,100 mg/l. This solution is sprayed on the spent ore utilizing the same sprinkler system as is used for leaching. When the 24-hour effluent average reaches 0.2 mg/l free cyanide, based on hourly samples, the heap is ready for disposal by removing the spent ore from the pad by front end loaders and hauling it in belly dump haul trucks to the Bradley mill tailing site. There, it is spread out in thin layers, 0.3 to 0.6 meters (1 to 2 feet) deep, on top of the old tailings and left undisturbed for 10 days to allow for degradation of the remaining cyanide. The old tailings cover amounts to 3 or 3.7 meters (10 or 12 feet) after several lifts have been placed. Samples of the material in the disposal area after 8 to 10 days indicate that, on the average, there is a decrease of approximately 50 percent of the free cyanide. Natural degradation, which has not been confirmed by experimentation, is thought to involve a combination of mechanisms including volatilization, oxidation, biodegradation, photodecomposition, and formation of stable complexes with available metal cations.

Monitoring

Fifteen surface water monitoring stations are sampled at least three times during the June to October operating season. The samples are analyzed for 20 parameters (Table A-1).

FIGURE A-3
CHLORINATION CIRCUIT AT STIBNITE MINE

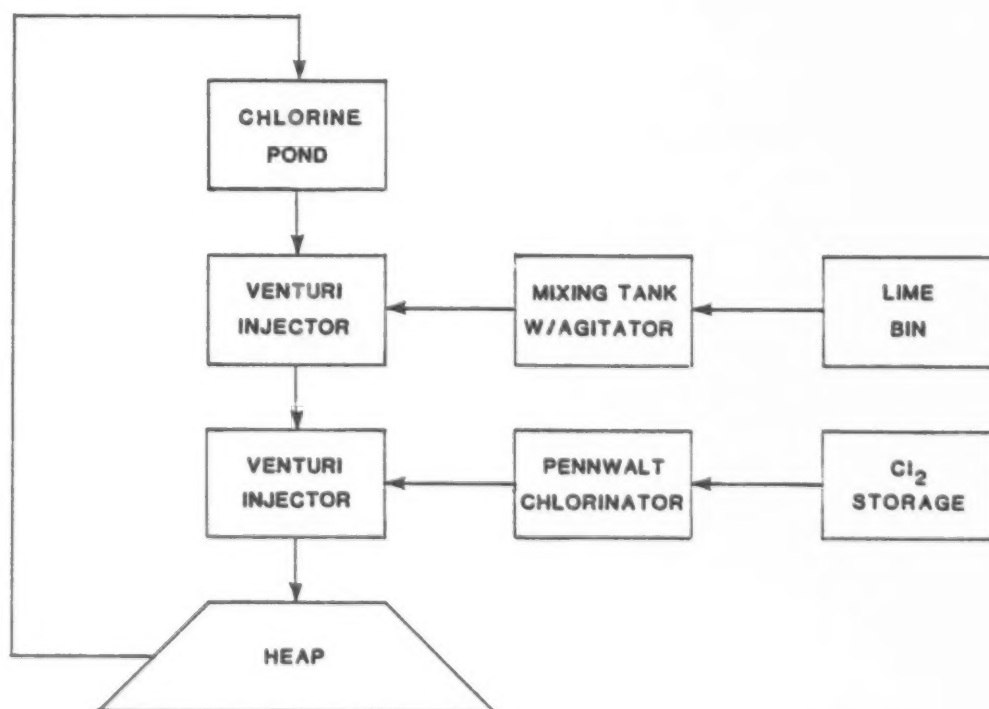


Table A-1
SURFACE WATER MONITORING PARAMETERS

pH (lab)	Chlorine residual (field)
Conductivity	(4 Sites only)
Temperature (Field)	Total coliform
Total Kjeldahl nitrogen	Turbidity (lab)
Sulfate	Total suspended solids
Antimony	Nitrate
Sodium	Total phosphorous
Lead	Arsenic
Zinc	Hardness (CaCO_3)
Free cyanide (5 sites only)	Mercury

In addition, four sites are sampled every 7 days and analyzed for turbidity, free cyanide and once a month, for arsenic and total suspended solids. Ground water is monitored by sampling 10 shallow wells three times each operating season on the same schedule as the surface water samples. These analyses are conducted by an independent laboratory. The operator analyzes free cyanide, pH, residual chlorine in some of the wells twice weekly. Other wells and the pad subdrain are sampled daily. During the off-season, these wells are sampled and analyzed monthly. The camp domestic water well and the plant utility well are sampled three times each operating season and analyzed for eleven parameters (Table A-2). They are also monitored for U.S. EPA drinking water parameters in the spring and early fall of each operating season.

Table A-2
CAMP DOMESTIC WELL AND PLANT UTILITY WELL
MONITORING PARAMETERS

Cyanide	Calcium
Aluminum	Magnesium
Arsenic	Sodium
Antimony	Iron
Hardness	Mercury
pH	

Consumables

Supplies and consumables for the facility must be transported over 130 kilometers (80 miles) of winding mountain roads which run alongside major tributaries of the Salmon River. To minimize the chance of accident and loss of dangerous materials to the surrounding environment, enclosed vans preceded by a pilot car are used to deliver chemicals to the site. To diminish confusion and improve coordination with suppliers and agencies involved in the area, Pioneer has elected to work with only one vendor for the chemical supplies needed at Stibnite.

Facility Access

Access to the leaching and process area is restricted by means of an 2.4-meter (8-foot) high fence. The area is marked, advising unauthorized personnel to stay out. The fence is maintained such that wildlife access to the site is unlikely.

Winter Shutdown

The Stibnite region receives more than 790 millimeters (31 inches) of annual precipitation. The majority of the precipitation is snow and occurs between the months of December and April. The spring runoff must be handled as part of the shutdown procedure in the fall. All four ponds at the plant are drained. During the winter months, the pond levels are monitored and as the water levels rise, the ponds are

pumped. The discharge criteria for excess water require that during the 24-hour sampling period the free cyanide concentration to be less than 0.2 mg/l. Sampling takes place during discharge and if a sample exceeds 0.2 mg/l of free cyanide, the free cyanide is removed by the hypochlorite treatment. The discharge solution is pumped from the ponds at a rate of 0.01 cubic meters per second (200 gallons per minute) through 10-centimeter (4-inch) PVC pipe for a distance of 2,000 meters (5,000 feet) to the old tailings area. It is discharged on the tailings as a land application by spraying in a sprinkler system, which further oxidizes any residual cyanide.

WHARF RESOURCES - BLACK HILLS, SOUTH DAKOTA

Wharf Resources operates a heap leaching facility in the Bald Mountain District of the Black Hills, southwest of Lead, South Dakota. The information presented below on Wharf Resources is based on a site visit and personal communication with Mr. Luther Russell of Wharf Resources. The Bald Mountain District is one of several mining districts in an area in which perhaps hundreds of mines of various sizes, mostly small, tried to achieve success. While perhaps best known for its gold and silver production, the Black Hills were also mined for other metals such as tin and tungsten. However, the most successful mining has been for gold and silver. Regional geology and general information on ore bodies that may be leachable in the Black Hills is discussed in Chapter 3.

Prior mining activity on the claims, now under the control of Wharf Resources, was by the Portland Mining Company which operated until 1959. The pits worked by Wharf Resources include the Annie Creek pit, which is now essentially mined out but does have perhaps 27,000 metric tons (30,000 short tons) of leachable ore remaining. The present mining activity is in the Foley pit which is located near the Terry Peak Ski Area. In the immediate vicinity there are a few newer ski-resort condominiums.

The Portland Mining Company operated the property as an underground mine, while Wharf is presently mining by open pit methods. Consequently, underground workings are frequently encountered. In fact, in the Annie Creek pit, many of the old drifts open into the pit walls. Wharf began operations in 1982 and currently ore reserves are estimated at 4.5 million metric tons (5 million short tons) at a stripping ratio of 2 to 1 waste to ore, with an ore grade of about 1.7 grams per metric ton (0.05 troy ounces per short ton) gold.

Mining

As stated, mining is by conventional open pit with advanced drilling to a 0.6 meter (2-foot) depth on 3.7-meter (12-foot) centers. The blast holes are sampled and assayed for gold and silver content to determine if the block is ore or waste. The drill holes are loaded with ANFO and broken by blasting to nominal 46-centimeter (18-inch) rock. The powder factor is approximately 0.3 kilogram per metric ton (0.5 pound per short ton) of broken rock. The broken ore is loaded by front end loaders into 45-metric ton (50-short ton) trucks. There are five such trucks to haul waste and ore. The haul distance to the waste area is approximately 900 to 1,200 meters (3,000 to 4,000 feet). The haul of ore to the leach pad is approximately 2,000 meters (7,000 feet). Three 8-hour shifts per day, 5 days a week are used for the mining operations with 4,000 metric tons (4,000 short tons) of ore and 7,000 metric tons (8,000 short tons) of waste produced. The waste area presently in use is known as the Ross Spring area. A new waste disposal area is being cleared in the area of Squaw Creek. The waste contains no sulfide material and, in general, the rock has been found to be basic so there is no acid generation in the heap or waste piles. Mining is conducted 10 months of the year. Advanced mine stripping is done in the remaining two cold months. For purposes of noise level control, blasting is carried out only between 9:00 am and 4:00 pm.

Crushing

Two-stage crushing of the ore to less than 3.8 centimeters (1.5 inches) is accomplished with portable crushing plants. Ore is fed via a 1.5- by 5.5-meter (5- by 18-foot) apron feeder and a feeder to a primary jaw crusher and reduced in size to less than 15 centimeters (6 inches) (Figure A-4). Undersize ore from the wobbler feeder is moved by conveyor to the crushed ore pile. The crushed ore is moved by conveyor to a 450-metric ton (500-short ton) coarse ore surge pile equipped with a plate feeder delivery to a second conveyor that moves ore up to a 2- by 5-meter (5- by 16-foot) double deck vibrating screen with 6.4 centimeter (2.5 inch) square openings on the upper deck and 3.8- by 6.4-centimeter (1.5- by 2.5-inch) on the lower deck. Undersize ore from the screen, less than 3.8 centimeters (1.5 inches), is conveyed to a fine ore pile. Screen oversize is directed to a cone crusher and moved by a conveyor to the conveyor feeding the vibrating screen ahead of secondary crushing. The ore breaks uniformly with minimal generation of fine material. As the ore is conveyed to the fine ore storage pile, lime is added at a rate of about 1 kilogram per metric ton (2 pounds per short ton). This is necessary to ensure a high pH during the cyanide solution leaching step.

Pad and Heap Design and Description

Ore is transferred from the fine ore surge pile by a front end loader and a 45-metric ton (50-short ton) offroad truck to the heap. The heaps are approximately 6.1 hectares (15 acres) in area and hold about 1.4 million metric tons (1.5 million short tons) of ore. Seven lifts, each 4.6 to 5.4 meters (15 to 18 feet) in height, for a total height of about 30 meters (100 feet) comprise the heap.

The soil base for the pad is cleared and graded to the desired profile. It is compacted and 20 centimeters (8 inches) of clay are placed on the compacted base (Figure A-5). The clay is compacted and the surface cleared of any rocks. A 30-mil PVC liner is placed on top

**FIGURE A-4
WHARF RESOURCES
BLOCK FLOW DIAGRAM**

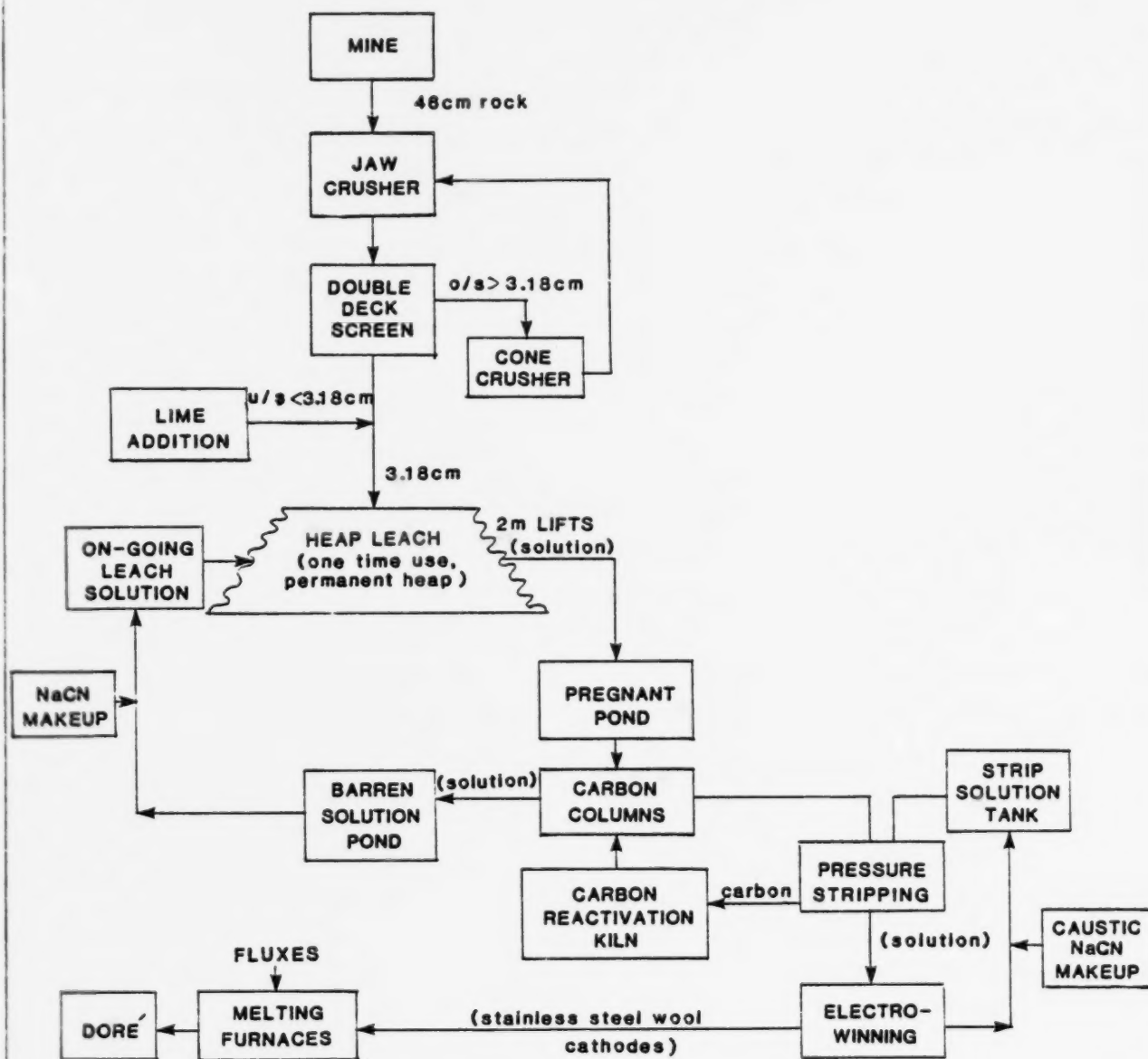
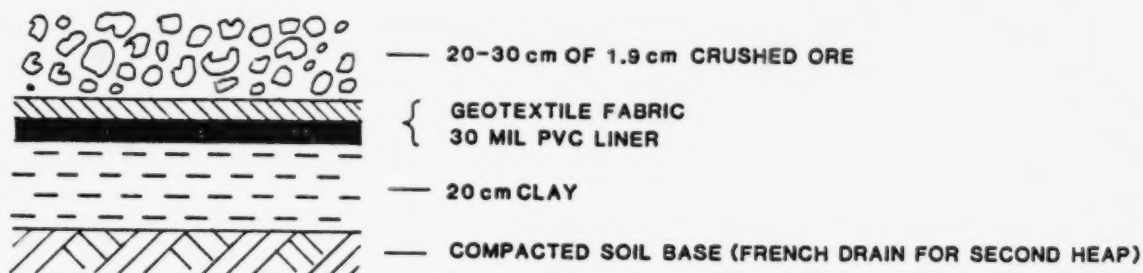


FIGURE A-5
TYPICAL PAD AND POND LINERS AT ANNIE CREEK MINE
PAD SECTION



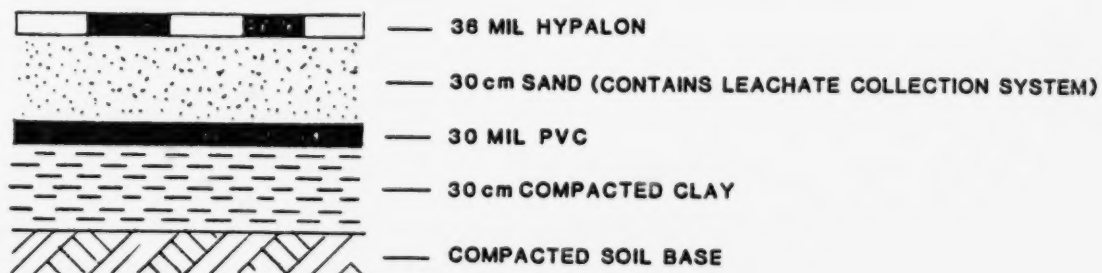
CONTINGENCY POND LINER SECTION



PROCESS POND AND OVERFLOW LINER SECTION



NEUTRALIZATION POND LINER SECTION



of the clay and the seams are carefully sealed. A geotextile fabric is laid on top of the PVC liner to serve as protection for the liner and 20 to 30 centimeters (8 to 12 inches) of 1.9-centimeter (0.75-inch) crushed ore are placed on the geotextile fabric to provide for drainage.

In the first production heap, an 20-centimeter (8-inch) perforated pipe was run down to the pad base surface to provide an intermediate drain. The second heap presently under construction has additional drain lines and will drain from the center line to the edges of the pad. The pad is surrounded by a 3-meter (10-foot) buffer zone and the pad edges are bermed to 0.6 meter (2 feet) to prevent escape of any runoff from the heaps. The buffer zone will also minimize solution spray drifting from the pad area.

Initially, solution runoff from the heap was directed to the storage ponds by lined, open ditches. The solution now moves to the pond by pipe.

Forty-five-metric ton (50-short ton) trucks move ore from the fine ore pile to the heap. There it is carefully dumped to minimize segregation. It is spread by a dozer until a lift is nearly completed. When room on each lift becomes available to establish the leaching lines, the area will be leached. In the meantime, building of the heap continues while leaching begins. When the first lift is completed, the second lift is started, with access provided by a roadway along the edge of the first lift. The next lift is smaller than the proceeding lift by the width of the roadway. In the first 1.4-million-metric ton (1.5-million-short ton) heap, which is now completed and in full leach, seven such lifts were used and the heap resembles a stepped pile with each subsequent lift smaller in area. A first lift for the second heap is well advanced and preparations of the pad base and liner are also well underway.

Leaching

As stated earlier, leach lines are draped over the pile on about 10-meter (40-feet) spacing. Sinninger wobbler sprinklers are 10 meters (40 feet) apart on each of these lines. The leach solution is a cyanide solution with a pH range of 10 to 11, typically 10.2, and the sodium cyanide content of the ongoing solution is about 500 mg/l. The pumping rate to the completed heap now in operation is 0.038 to 0.044 cubic meters per second (600 to 700 gallons per minute). The leach solution which has percolated through the heap is directed to the pregnant liquor storage pond. The pregnant solution contains 1 mg/l of gold, 0.003 ppm mg/l silver, 2 to 3 mg/l of iron, 2 to 3 mg/l of arsenic, and traces of cobalt, lead, nickel, and mercury.

The leach procedure involves moving the leach lines when the gold content of the solution coming off the heap begins to decrease (typically about every 20 days). The lines are moved an appropriate distance at that time and the leaching action continues. According to the process plant manager, if the heap pile is inactive after leaching, placing the leach lines back in the same area again results in increased gold pickup for a short period of time.

The anticipated life of a heap, including heap building followed by leaching, is approximately 3 years. Continuous operation is desired, i.e., upon completion of the heap building, completion of leaching the entire heap closely follows.

Solution from the heap is piped by gravity to the pregnant liquor storage pond. The pregnant pond and three other ponds are adjacent to the process plant.

Pond Design

The four ponds include a 13,000-cubic-meter (3.5-million-gallon) pregnant solution pond, a barren pond of about 19,000-cubic-meter (5-million-gallon) capacity, an overflow pond of about 19,000-cubic meter (5-million-gallon) capacity and a contingency pond of about 34,000-cubic-meters (9 million gallons). The pregnant pond is the highest topographically, followed by the barren pond, the overflow pond

and the contingency pond. They are arranged so that the upper pond can overflow into the lower ponds before overflowing the entire pond system.

The ponds are constructed by removing the appropriate amount of soil, sloping and compacting the sides and base, then placing 20 centimeters (8 inches) of clay on the prepared soil. The clay is compacted and a 30-mil hypalon liner is placed on top of the clay (Figure A-5). For the contingency pond, only the clay liner is in place. The very low permeability of the clay liner (approximately 10^{-7} centimeters per second) provides ample protection from leakage from the pond through the liner if an event required use of the contingency pond. Lysimeters are placed in the clay under the hypalon liner and are monitored to detect any leakage through the liner. The ponds are checked annually for any leakage through the hypalon and appropriate repairs made if any leaks are found.

A fifth pond is being constructed some distance away from the other ponds. It will be designed to hold about 23,000 cubic meters (6 million gallons). Wharf Resources is required by the state to double-line the pond with a soil base, 30 centimeters (12 inches) of clay, a 30-mil PVC layer, 30 centimeters (12 inches) of sand, a geotextile fabric layer and finally a 30-mil hypalon liner. The purpose of the pond is to hold a cyanide neutralizing solution which, following completion of the leaching step, will be circulated onto the heap to destroy the cyanide. At the present time, a hydrogen peroxide solution is being considered for that application.

The leaching operation takes place approximately 10 months of the year. The other 2 months present problems because the leach lines cannot be moved due to snow and pipe freeze-up. However, Wharf Resources has noted that the temperature within the heap during the winter can be as high as 2.8°C (37°F) as a result of chemical reactions underway in the leaching process. It is anticipated that Wharf Resources will try to operate during the winter of 1986.

Recovery Plant

Solution from the pregnant pond is pumped into the recovery plant, which uses carbon adsorption to remove gold from solution. The carbon column section is standard design and configuration. The solution enters the uppermost carbon columns, which is a tank approximately 3.7 meters by 1.8 meters (12 feet by 6 feet). The solution is pumped through the tank at the rate of 45 liters per second (720 gallons per minute). Each of the tanks contains approximately 1 metric ton (1 short ton) of activated coconut carbon and the solution upflows through carbon, cascades down to the next tank until it completes a circuit of five tanks. The flow is countercurrent. While the solution flows down through the five columns of carbon, the carbon from the lower tank is advanced to the next tank upstream. The carbon from the first column is essentially depleted of gold.

Carbon Stripping

The loaded carbon from the first adsorption column is transferred to five pressure stripping vessels where the solution contacts the stripping solution containing 15 kilograms caustic per metric ton (30 pounds caustic per short ton) of solution and 1.5 kilograms of sodium cyanide per metric ton (3 pounds of sodium cyanide per short ton) of solution. The stripping temperature is about 130° C (270° F). Stripping retention time is about 12 hours. The carbon is reactivated by heating in a gas-fired rotary kiln at a rate of 110 kilograms (250 pounds) per hour to a temperature of 590° C (1,100° F).

Wharf Resources has found that it is not necessary to acid wash the reactivated carbon, as is the practice of most operations. Instead, simple soft water wash is adequate to return the carbon to its normal activity. The stripped solution containing the gold at a concentration of 86 grams per metric ton (2.5 troy ounces per short ton) of solution is electrowon by standard procedures on stainless steel wool. When the wool cathode reaches a gold content of 7,000 to 10,000 grams per kilogram (100 to 150 troy ounces per pound), the cathode is harvested and then converted to dore in a propane-fired

furnace with the addition of appropriate fluxes. The dore assays approximately 90 percent gold and 10 percent silver. The dore is shipped to a custom refinery for separation and refining to marketable gold.

Water Use

After the initial process water is obtained, an average of 0.004 cubic meters per second (70 gallons per minute) is used to augment the water supply for the leaching operation due to 5 to 10 percent evaporation losses.

Spill Containment

The entire leach and process plant area is graded so that any spills will run to the pond system. Monitoring wells are positioned around the property and lysimeters are used to detect possible leaks through the pond liner.

Monitoring

The monitoring program for potential leaks at the facility uses lysimeters underneath the pads and ponds. The pad currently under construction will have a gravity drain system under the liner which will open to the pregnant solution ponds. A neutralization pond currently under construction will use a similar detection system but will be equipped with a standpipe for sampling. Each of the units is (or will be) sampled monthly if there is any flow.

There are eight surface water sampling stations associated with the property. They are positioned so as to be able to sample both upgradient and downgradient from the facility. Their locations were selected on the basis of major drainage pathways to and through the site.

For monitoring ground water there are 6 wells in excess of 30 meters (100 feet) in depth. Their locations are associated with the ground water pathways in the area.

Surface water stations and the ground water wells are sampled quarterly and the samples are analyzed by a State of South Dakota certified laboratory. Some 20 parameters are involved in these analyses including metals (Al, As, Cd, Cu, Fe, Pb, Mn, Hg, Se, Ag, Zn), BOD, TSS, TDS, carbonate, alkalinity, cyanide, and pH.

The analytical results are submitted to the state for review. To date, Wharf Resources detected one small leak in their system. A liner in the barren pond had a small tear and some cyanide solution seeped into the clay liner below. There was also a reported overflow about the same time during spring runoff, from the barren pond to the overflow pond, which had only a clay liner at that time. It is understood that there was no release of solution from the overflow pond; the clay liner in that pond effectively prevented any loss of solution to the ground water.

Site Power Supply

Power is provided by the Black Hills Power and Light Company and a backup diesel generator is onsite for handling pumps in the event of emergencies.

Surface Water Runon Control

Surface water is diverted around the plant area by diversion ditches. The ditches are sized for a 480- millimeter (19-inch), 6-hour probable maximum precipitation event as required by the State.

Site Access

The entire area is enclosed by a 2.4-meter (8-foot) fence to limit wildlife and human access. The gate leading into the property has an around-the-clock guard.

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- Stotts, W. G. 1985. Handling cyanide at Superior Mining Company's Stibnite Heap Leaching Operation. In D. Van Zyl (ed.). Cyanide and the Environment. Proc. of a Conference. Tuscon, Ariz. Dec. 11-14, 1984. Department of Civil Engineering, Colorado State University. Ft. Collins, Colorado.

APPENDIX B

CYANIDE CHEMISTRY

OVERVIEW

Cyanide may occur in many forms. The forms of cyanide relevant to a discussion of heap leach mining are:

Free cyanide - Cyanide ion (CN^-) and molecular hydrogen cyanide (HCN). The distribution between cyanide and HCN is dependent on pH with HCN predominant below pH 9.36 (20° C).

Simple cyanide - an alkali or metal cation and cyanide. An example of a soluble simple cyanide is sodium cyanide (NaCN), which is used in process solutions at heap leach operations.

Complex cyanide - metal cyanide complexes and their salts. Metal cyanide complexes are divided based on their stability into weak complexes containing zinc or cadmium, moderately strong complexes containing copper, nickel, or silver, and strong complexes containing iron, cobalt, or gold. The salts are relatively insoluble.

Cyanogenic glycosides - organic compounds introduced naturally into the soil which release cyanide upon hydrolysis. Plants are one of the most common sources.

Methods for measuring cyanide in water and the species of cyanide detected by each method are:

Free cyanide - measures the amount of HCN and CN^- .

Weak acid dissociable cyanide - measures free cyanide, and complexes of Cd, Cu, Ni, Ag, and Zn.

Total cyanide - measures free cyanide, weakly acid dissociable cyanide and most inorganic complex cyanides including Fe but excluding Au, Co, and some of the Pt metals.

Cyanide amenable to chlorination - measures the difference between total cyanide concentration before and after chlorination.

Researchers have been experimenting with different types of leaching and analytical procedures for cyanide measurement in solid samples such as spent ore.

Cyanide is a very reactive and relatively short-lived contaminant. Processes which tend to degrade or transform free cyanide in the environment are volatilization of HCN, reaction of cyanide to form ammonia and formate, oxidation, complexation with metallic ions, biological activity, conversion to thiocyanate (SCN^-) and sorption. Cyanide may be released from simple and complex cyanides depending on the stability of the specific compound or complex. In addition, iron or cobalt cyanide complexes, which are strong complexes, may undergo photochemical degradation by sunlight and release free cyanide. Cyanide released from simple and complex cyanides will be subject to degradation or transformation processes.

Volatilization is probably the most significant process in the natural degradation of cyanide in surface waters. Generally, free cyanide would be more mobile in surface waters with higher pH, lower temperature, lower levels of metals and sulfide, organic and inorganic suspended matter, and which have little interaction with sediment. Surface water bodies with stagnant, deep conditions and little surface area would promote high mobility of cyanide. Volatilization rates of HCN from ground water may be less than those from surface water. Other processes that tie up cyanide, such as sorption and complexation, may be much more important in limiting the mobility of cyanide in ground water than in surface water. Reaction of cyanide to ammonia and formate may also be an important process to reduce concentrations of cyanide in ground water.

Cyanide is more mobile in soils with anaerobic conditions. The limit for effective microbial degradation of cyanide was found to be 2 mg/l based on studies of a sewage waste stream (Coburn, 1949). Cyanides and cyanide-yielding compounds such as fertilizers and pesticides

applied to aerobic soils readily degrade (Fuller, 1985). Other factors affecting the mobility of cyanide in soil are clay content, depth of soil, content of iron oxides or other metal oxides, pH, and presence of organic matter. Mobility of cyanides is greatest in soils with high pH and low clay content.

The basic chemical process used in a heap leach mining operation is the complexation of Au and Ag from the ore with a sodium cyanide solution. One of two processes, carbon adsorption or zinc precipitation, can be used to recover the precious metals from the pregnant solution.

Neutralization, or a rinsing of the ore heaps, is used to reduce the levels of cyanide remaining in heaps after the ore is spent. Various western states require that the rinsing procedure continue until the cyanide concentration is reduced to a specified level or a certain pH is obtained. The final cyanide concentrations specified by states using free cyanide analyses ranges from 0.2 to 5 mg/l, and from 0.01 mg/l to 100 mg/l in states using total cyanide analyses. Although little data is available, sampling of heaps after the rinsing procedure is completed generally shows less than 10 mg/kg of free cyanide remaining in the heaps. Subsequent sampling shows a decrease of cyanide with time.

A variety of methods are used to destroy cyanide in process solution either during operation or upon closure, and rinsing solution used to neutralize the spent ore heaps. Treatment processes that are, or may be, used at leaching operations are natural degradation, alkaline chlorination, hydrogen peroxide, Inco process, and biological treatment.

Heap leach mining wastes contain free cyanide (HCN and CN^-), metal cyanide complexes, and salts of metal cyanide complexes. The amount of free cyanide in these wastes is dependent upon the rate of volatilization of HCN to the atmosphere. An important control on volatilization is pH; below a pH of 9, HCN is predominant over cyanide ion.

Metal cyanide complexes such as iron, copper, zinc, nickel, cobalt, and cadmium, which are the most common at gold and silver operations (Huiatt, 1985), decompose and release cyanide ion at varying rates. Zinc and cadmium complexes, the least stable complexes, readily decompose during the rinsing process as free cyanide decreases. Strong complexes such as iron cyanide complex may remain in the spent ore. Iron cyanide complexes have been found to degrade in solutions exposed to ultraviolet light, but the photochemical effect on the solid species is unknown. Iron, nickel, cobalt, and copper salts of iron complex cyanide ions are very sparingly soluble and release very small amounts of free cyanide in the spent heap pile.

In addition to volatilization directly from the mining wastes, there is a secondary transport process whereby cyanide and any soluble metal cyanide complexes may be leached from the mining wastes and transported into the environment if uncontained. The accidental release of cyanide process solution is also possible. Several chemical and biological processes have the potential to attenuate cyanide when it is released to the environment.

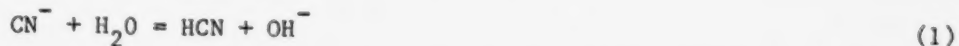
CHEMICAL FORMS OF CYANIDE

A large number of organic and inorganic chemical compounds contain cyanide. Cyanide occurs as a cyano group (CN) in the molecular structure of the compound. In solution, the cyanide ion (CN^-) is a negatively charged, diatomic species, which may complex with both inorganic and organic compounds. Since most metals tend to form positive ions, they may readily react with cyanide. The characteristics of cyanides, particularly the high level of stability for some of the metal cyanide complexes, can be explained by its bonding properties. For the purposes of this report, four different forms of cyanide, free cyanides, simple cyanides, complex cyanides, and cyanogenic glycosides (organic compounds containing cyanide) will be discussed below.

Free Cyanide

Free cyanide in solution is the total concentration of cyanide ion (CN⁻) and dissolved molecular hydrogen cyanide (HCN). Hydrogen cyanide is a colorless gas or liquid with a boiling point of about 25.5 °C (77.9° F). The gas is less dense than air and flammable.

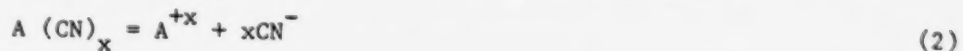
HCN or hydrocyanic acid, a weak acid, has a dissociation constant of 4.365×10^{-10} at 20 °C (68° F) for the hydrolysis reaction between cyanide ion and water:



The relative amounts of CN⁻ and HCN as predicted by this relationship are strongly dependent on the pH of the solution (Figure B-1). The concentration of CN⁻ and HCN are equal at pH 9.36, the pK (log of the equilibrium constant) of HCN at 20 °C (68° F) (Broderius, 1974). At pH values below 9.36 and at 20° C (68° F), most cyanide exists as molecular HCN; 69.6 percent at pH 9; 95.8 percent at pH 8; and greater than 99 percent at pH 7. In natural waters most of the free cyanide concentration would be in the form of HCN. Since HCN has a high vapor pressure it readily evaporates depending on the solution concentration, temperature, and pH. Higher temperatures and solution concentrations, and lower pH values promote generation of gaseous HCN.

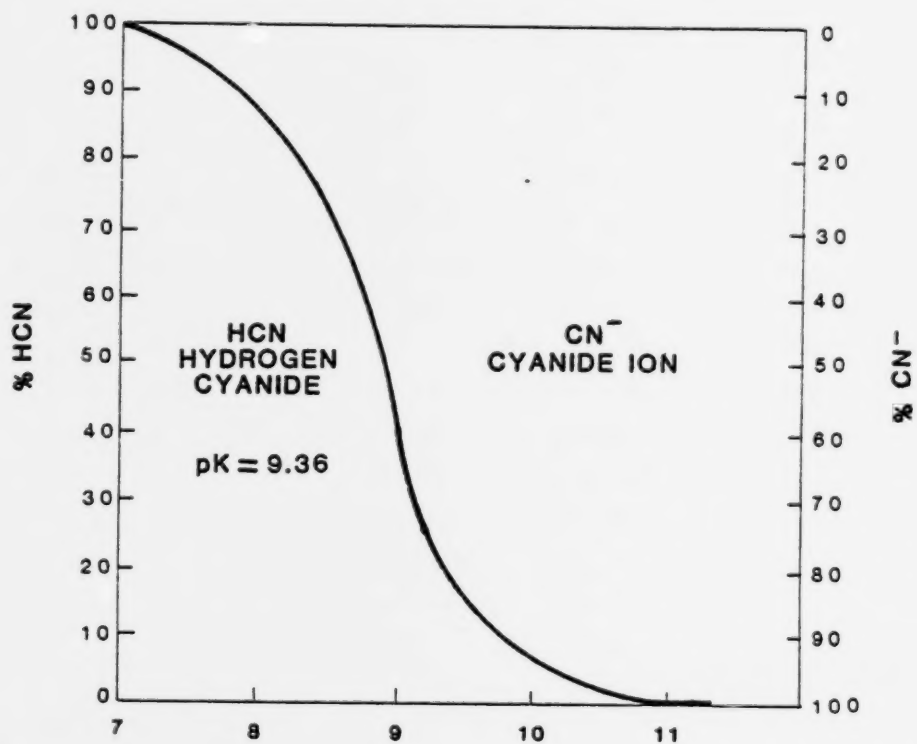
Simple Cyanides

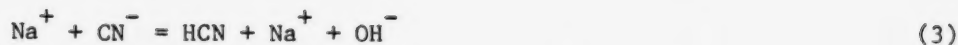
Simple cyanides consist of an alkali (sodium, potassium) or metal cation and cyanide. They can be represented by the formula A(CN)_x, where A is an alkali or metal, and x, the valence of A, represents the number of cyano groups present. Solubilities of the simple cyanides are a function of pH and temperature. Soluble compounds (particularly the alkali cyanides) ionize to release cyanide as shown:



Cyanide ions released would undergo hydrolysis as shown in equation (1). An example of a simple cyanide used in heap leaching mining operations is sodium cyanide (NaCN) which would dissolve and readily hydrolyze as shown:

FIGURE B-1
THE EFFECT OF pH ON DISSOCIATION
OF HYDROGEN CYANIDE





Complex Cyanides

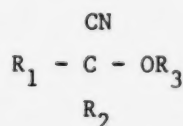
Alkali-metallic cyanides are represented as $\text{A}_y\text{M}(\text{CN})_x$, where A is the alkali such as sodium or potassium, y is number of alkalies, M is the heavy metal (ferrous or ferric iron, gold, copper or others), and x is the number of cyano groups. The valence of the alkali (A) taken y times plus the valence of the metal (M) is the value of x. Soluble alkali-metallic cyanides dissociate to release the metal cyanide complex ion, $(\text{M}(\text{CN})_x)^{-yw}$, by the reaction:



where w is the oxidation state of A in the original alkali-metallic cyanide compound. The metal cyanide complex ion released may undergo further dissociation and release cyanide ion. Another type of compound with a similar formula is the complex ferro or ferric cyanide salts, where A and M would be a heavy metal and either Fe^{2+} (ferrous) or Fe^{3+} (ferric), respectively. Some examples of metal cyanide complex ions which may be found in process solutions of heap leach mining operations are $\text{Fe}(\text{CN})_6^{3-}$, $\text{Cu}(\text{CN})_2^-$, and $\text{Zn}(\text{CN})_4^{2-}$.

Cyanogenic Glycosides

Organic compounds yielding cyanide are introduced naturally into the environment, particularly the soil. One of the most common natural sources is from plants. A large number of plants (800 species) naturally synthesize cyanogenic glycosides (Knowles, 1976). The general formula is:



where R_1 = an alkyl or aryl group

R_2 = a hydrogen atom or methyl group

R_3 = usually, D-glucose.

One of the best known cyanogenic glycosides, called amygdalin, occurs in seeds and leaves of many members of the Rosaceae (rose) family (Kingsbury, 1964). Many common vegetables also contain cyanogenic glycosides such as maize, millet, field bean, kidney bean, sweet potato, and lettuce (Oke, 1969). Generally, the glycoside is harmless, but becomes toxic only when in vivo conditions permit hydrolysis of the compound to liberate hydrogen cyanide (refer to Appendix C for a discussion of toxicity).

ANALYTICAL METHODS

Standard methods for measuring cyanide that are most relevant to the mining industry are described below. These methods include total cyanide, free cyanide, weak acid dissociable cyanide, and cyanide amenable to chlorination. Several problems associated with the analytical methods are also presented.

Methods for Water Samples

Total Cyanide

The acid reflux/distillation method measures the free cyanide and the cyanide contained in complex iron cyanides, weakly acid dissociable cyanide, and most inorganic complex cyanides except gold, cobalt, and some of the platinum metals. The ASTM method (1981) uses a catalytic agent to facilitate the breakdown of the metal cyanide complexes. The hydrogen cyanide liberated by the distillation is collected in an alkaline absorbing solution and can be measured by titration, colorimetry, or specific ion electrode. The lower limit of detection for the three methods are 1.0, 0.03, and 0.03 mg/l, respectively.

Modifications to the ASTM method to eliminate interferences caused by thiocyanate have been developed. In the acid distillation technique, decomposition agents such as hydrochloric acid/hydroxylamine, tartaric acid, or phosphoric acid (Knechtel and Conn, 1981; Huiatt et al., 1983) are used.

The EPA procedures were last revised in 1984 as Method 335.2 (STORET No. 00720). This method is either a titrimetric or a spectrophotometric analytical procedure similar to ASTM. Single laboratory precision is reported as 85 percent and 102 percent recovery at 0.28 and 0.62 mg/l CN, respectively. These recoveries were apparently reported for water samples.

Free Cyanide

The methods for determining free cyanide include solvent extraction or sparging the HCN from solution and collecting it for later measurements (Broderius, 1975, Montgomery et al., 1969; Schneider and Freund, 1962).

Weak Acid Dissociable Cyanides

The method accepted by ASTM as a standard procedure for determining weak acid dissociable cyanides is called Method C, a variation of one proposed by Roberts and Jackson (1971). The reagents used in the distilling flask are acetic acid-sodium acetate solution buffered at pH 4.5 and zinc acetate. Gonter (1975) reported that cyanide was totally recovered from cadmium, copper, nickel, silver, and zinc complexes. Test work reported by Conn (1981) suggests that some (two percent) breakdown of ferrocyanide could occur. No interference occurs in this method by the presence of thiocyanate.

Cyanide Amenable to Chlorination

Cyanide amenable to chlorination is the difference between total cyanide measurements before and an alkaline chlorination treatment. Chlorination treatment oxidizes cyanide, HCN, cyanide from weakly dissociated and moderately strong metal complexes, and thiocyanate, but does break down the iron cyanide complexes or other stable complexes. Refer to the section entitled, Complexation with Metallic Ions for the stabilities of metal cyanide complexes. The sample is separated into two portions; one is analyzed for total cyanide and the other is analyzed for total cyanide after a treatment with sodium hypochlorite at an alkaline pH for one hour. EPA uses Method 335.1 (STORET No. 00722) to determine cyanide amenable to chlorination.

Methods for Solid Samples

EPA Method 9010 (U.S. Environmental Protection Agency, 1982) may be used to analyze for total and chlorine amenable cyanides in solid wastes or leachate. A draft testing method has just been released by EPA to determine whether a waste is hazardous due to cyanide reactivity (U.S. Environmental Protection Agency, 1986). The memo stated that on an interim basis wastes releasing more than 250 mg HCN/kg waste should be regulated as hazardous waste. Other methods for cyanide analysis in environmental samples are currently being tested. The literature shows that particular methods are suited to specific types of samples depending on the sample composition. Hendrix et al. (1985) has developed a method producing reproducible results suitable for tailings samples. After drying and thorough mixing, 5 grams of sample were mixed with 20 milliliters of 1 N NaOH and about 200 milligrams of PbCO_3 , and filtered into a distillation flask. The filtrate was analyzed for total cyanide by the ASTM method. Free cyanide was analyzed directly without the caustic filtration pretreatment. J.L. Hendrix (University of Nevada at Reno, personal communication, 1986) is also developing analytical methods to determine the amounts of specific metal cyanide complexes present.

Several different leachate solutions, deionized water, 1 N KNO_3 in water, and 1.25 N NaOH in water, were tested on samples from heap leach piles by Ray (1985). The procedure for analysis consisted of leaching a 20 gram sample in 100 milliliters of leachate solution for 24 hours in the dark. After leaching, the sample was filtered (Whatman GF/C or equivalent) until the final volume was 100 milliliters. The leachate was then analyzed by the distillation/destruction method with a colorimetric finish. The results for direct analysis (0.5 gram sample in distillation flask) and the three leachate methods are presented in Table B-1. Only the NaOH solution solubilized cyanide at a level similar to that found in the direct analysis. The data also show that reproducibility of results is greatly increased with the larger sample sizes.

TABLE B-1
COMPARISON OF LEACHING METHODS
FOR TOTAL CYANIDE DETERMINATION IN SOLID SAMPLES

Run #	Direct Analysis ^{a/} (mg/kg)	Leaching Method		
		DI Water (mg/kg)	1 N KNO ₃ (mg/kg)	1.25 N NaOH (mg/kg)
1	45.2	0.8	0.6	142
2	125	0.6	0.4	47.9
3	77.5	<0.2	<0.2	43.2
4	57.3	<0.2	<0.2	109
5	179	0.6	<0.2	106
6	114	0.2	0.4	91.9
7	129			116
8	88.1			114
9	98.3			
10	170			
11	196			
12	104			
13	114			
14	59.9			
15	65.1			
Mean	108	0.4	0.2	96.2 ^{b/}
+ 1 S.D.	45.9	0.3	0.3	34.3

a/ Analysis of 0.5 g sample.

b/ If values from runs #2 and #3 are omitted, the mean is 113 ± 16.5 (+ 1 S.D.).

Source: Modified from Ray, 1985.

Several other examples which illustrate the diversity of methods used for solid samples are described below:

Engelhardt (1985) and Milligan (1985a) - 200-gram split of spent heap material (reprocessed tailings) was agitated for one hour with 200 milliliters of distilled water; after filtering, the pH was adjusted to 12.0 with sodium hydroxide, and then analyzed for free and total cyanide.

Stotts (1985) - 25 grams of spent heap material was placed in 50 milliliters of 20 percent NaOH solution and allowed to mix until delivered to the laboratory which was 12 to 24 hours later; solution was then analyzed for free cyanide.

The actual data from these examples on cyanide concentrations in spent heap leach piles is presented in the section, Cyanide in Spent Leach Piles.

Problems Associated with Analyses

Problems can occur with sample preservation for water samples containing solids. A clear, filtered sample preserved by the addition of sodium hydroxide to a pH of 12 and stored in the dark at 4° C (40° F) will be stable for at least two weeks (Huiatt et al., 1983). There is, however, no guaranteed method of preservation when solids are present (Conn, 1981). Samples with solids can be filtered and preserved or analyzed immediately. If a sample is known to contain sulfides, these should be removed by precipitation with lead carbonate before raising the pH for preservation.

There are many potential sources of interference in analytical determinations for cyanide including sulfides, oxidizing materials, thiocyanates, nitrate-nitrite, carbonate-bicarbonate, metal cations, aldehydes, fatty acids, and potential cyanide-forming materials. ASTM (1981) states that it is beyond their scope to describe procedures for overcoming all the interferences that may be encountered.

Some other problems that have been noted in the literature is that the cyanide ion-selective electrode can be attacked by cyanide solutions which causes inaccurate results (Frant, et al., 1972). Sulfide also causes problems by deactivating the surface of the electrode.

ENVIRONMENTAL FATE OF CYANIDE

Cyanide is a very reactive and relatively short-lived contaminant unlike many pollutants which may enter the environment. Research work on natural destructive mechanisms and rate of degradation for cyanide in the environment has begun recently. This section will focus on the transformation and degradation process for free cyanide, simple cyanides, complex cyanides, and cyanogenic glycosides thought to be most significant to the environmental aspects of a mining operation, and will conclude with a discussion of the factors influencing the mobility of cyanide in surface water, ground water, and soils.

Free Cyanide Transformation and Degradation Processes

Volatilization

The most important mechanism in the natural degradation of cyanide in water is recognized as volatilization of HCN (Simovic et al., 1985). As discussed above, molecular HCN is the dominant species of cyanide at pH values below 9.36. Since molecular HCN has a high vapor pressure, it can readily be volatilized to the atmosphere. Volatilization of HCN was found to be influenced by pH, temperature, interfacial surface area, and concentration (Dodge and Zabbon, 1952). Stripping coefficients were greatly reduced in stagnant solutions compared to agitated solutions since the process became dependent on molecular diffusion. The Chester Engineers (1977) studied dilute cyanide solutions in the range of 0.1 to 0.5 mg/l. The volatilization rate was $0.04 \text{ kg-mole/hr-m}^2\text{-atm}$ ($0.009 \text{ lb-mole/hr-ft}^2\text{-atm}$) in still waters, which is equivalent to the volatilization of $0.23 \text{ milligram CN/m}^2\text{-hr}$ ($0.021 \text{ milligram CN/ft}^2\text{-hr}$) from a 0.5 mg/l cyanide solution at room temperature. Volatilization rates in agitated waters were up to three times as fast.

Palaty and Horokova-Jakubu (1959) examined several factors, pH, temperature, solution depth, presence or absence of aeration and the rate of aeration, which affect HCN removal. The experiment involved HCN removal from an unbuffered, synthetic simple cyanide solution (KCN) at relatively low concentrations (10-50 mg/l CN) over a period of 11 days. The HCN removal rate increased with decreasing pH down to 5; an order of magnitude difference in the rates of HCN removal existed between aerated and nonaerated solutions; and a temperature increase of 10° C (50° F) from 0.8 to 11° C (33 to 52° F) caused the HCN removal rate to increase by greater than 40 percent.

Broderius (1977) conducted experiments on the volatilization of cyanide from natural water using concentrations of cyanide from 25 to 200 ug/l. The concentrations of cyanide in the water were measured during a 6-hour period, from which half lives of 8.8 to 55.5 hours were calculated for HCN disappearance. Disappearance of HCN became negligible when the samples were sealed and closed off from the atmosphere.

Simovic et al. (1985) studied the rate of cyanide degradation from a NaCN solution as well as from solutions containing a single metal cyanide complex and mixtures of metal cyanide complexes. Data from the solutions containing metal cyanide complexes and metal complex mixtures will be presented in the following section, Complex Cyanide Transformation and Degradation Processes. The initial total cyanide concentration for the NaCN solution at 4° C (40° F) was 200 mg/l. Air was bubbled through the solution and the solution was exposed to ultraviolet light. A phosphate buffer was added to maintain a constant pH of 7.0. The total cyanide concentration decayed to less than 1 mg/l after about 230 hours (9.6 days). The decay rate was initially much higher during the first 80 hours (2.1 mg/l per hour).

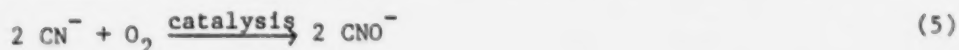
Reaction of Cyanide to Formate and Ammonia

Cyanide in water reacts to form ammonia and formate ions. Reaction products from an acidic cyanide solution are formic acid and ammonium salts and from a basic solution are formate salts and volatile ammonia. Reaction of HCN in strongly acidic solutions (pH <1) was

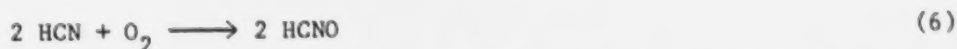
found to proceed with half-lives ranging from 10 to 1000 hours (Kreibler and McNally, 1929). The rate constants for the reaction of cyanide ion under alkaline conditions range from $2 \times 10^{-8} \text{ sec}^{-1}$ to $2 \times 10^{-6} \text{ sec}^{-1}$ at temperatures between 33 and 65° C (91 and 150° F) (Wiegand and Tremelling, 1972).

Oxidation

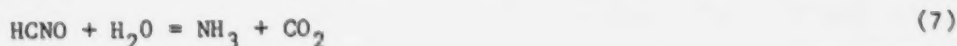
Direct oxidation of cyanide to cyanate (CNO^-) requires mineralogical, biochemical or photochemical catalysis. The reaction is:



Another route for oxidation is by hydrolysis to HCN and subsequent oxidation:



In water cyanic acid (HCNO) can hydrolyze to produce cyanate (CNO^-). Hendrickson and Daignault (1973) have shown that cyanic acid can be hydrolyzed to carbon dioxide and ammonia. The hydrolysis reaction is:



This reaction is pH dependent, and occurs at a pH up to 8.5, but is greatly accelerated at lower pH values. Further oxidation of ammonia would form nitrate.

According to Schmidt et al. (1981) oxidation processes may have accounted for about 11 percent of the decrease in cyanide from a relatively shallow holding pond for mill cyanide process solutions over a six month period during the warm season.

Complexation with Metallic Ions

Some 28 elements are capable of forming 72 possible metal cyanide complexes (Ford-Smith, 1964). The relative stabilities of some of the common cyanide complexes in water are given in Table B-2. The stronger or more stable the cyanide complex, the less free cyanide ion required to maintain it in solution and the less readily it dissociates to yield cyanide ions.

TABLE B-2

RELATIVE STABILITIES OF SOME CYANIDE COMPOUNDS
AND COMPLEXES IN WATER

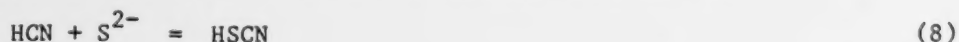
<u>Term</u>	<u>Examples of Cyanides in Processing Solutions</u>
1. Free Cyanide	CN^- , HCN
2. Simple Compounds	
a) readily soluble	NaCN, KCN, $\text{Ca}(\text{CN})_2$, $\text{Hg}(\text{CN})_2$
b) relatively insoluble	$\text{Zn}(\text{CN})_2$, CuCN, $\text{Ni}(\text{CN})_2$, AgCN
3. Weak Complexes	$\text{Zn}(\text{CN})_4^{2-}$, $\text{Cd}(\text{CN})_3^-$, $\text{Cd}(\text{CN})_4^{2-}$
4. Moderately Strong Complexes	$\text{Cu}(\text{CN})_2^-$, $\text{Cu}(\text{CN})_3^{2-}$, $\text{Ni}(\text{CN})_4^{2-}$, $\text{Ag}(\text{CN})_2^-$
5. Strong Complexes	$\text{Fe}(\text{CN})_6^{4-}$, $\text{Co}(\text{CN})_6^{4-}$, $\text{Au}(\text{CN})_2^-$

Source: Adapted from Scott and Ingles, 1981.

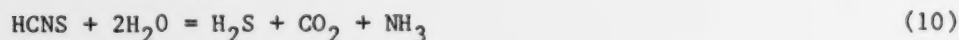
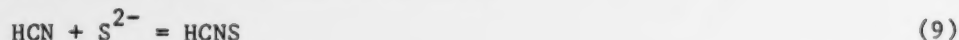
The dissociation of a complex cyanide ion involves a number of intermediate reactions, some of which may be rate limiting steps. At a given temperature, pH and the concentration of the complex ion influence the dissociation rate (Broderius, 1973). Rates of dissociation generally increase with either decreasing pH or decreasing total cyanide concentration. Dissociation of metal cyanide complex ions will be discussed further in the section, Dissociation of Metal Cyanide Complex Ions.

Biological Degradation

Biological destruction appears to be a significant means of reducing cyanide concentration. Numerous studies have shown that many bacteria, fungi, and algae are capable of utilizing cyanides, converting cyanide to carbon dioxide and ammonia. Biochemical degradation of cyanide may occur under both aerobic and anaerobic conditions over a wide pH range (Towill et al., 1978). Under aerobic conditions cyanide decomposes to carbon dioxide and ammonia biochemically as shown by either in equation (5) or (6), and equation (7). Cyanide decomposes to thiocyanate (SCN^-) under anaerobic conditions as shown:



Thiocyanate may hydrolyze to produce hydrogen sulfide, carbon dioxide and ammonia. Schmidt et al. (1981) suggests the general pathways for anaerobic decomposition are as follows:



Higher plants and animals have the capacity to metabolize sublethal doses of administered cyanide to thiocyanate (Towill et al., 1978). Activated sludge treatment can result in virtually complete removal of cyanide (Ludzack and Schaffer, 1962; Kostenbalder and Flecksteiner, 1969), but Raef et al., (1977b) thought that most of the loss of cyanide in such systems is due to stripping (volatilization).

Conversion to Thiocyanate

If sulfide (S^{2-}) or thiosulfate ($S_2O_3^{2-}$) is present in the environment, cyanide can react to form thiocyanate (SCN^-). This chemical process would occur where sulfide minerals are oxidizing. Metal thiocyanate complexes may be formed but the formation potential for metal cyanide complexes is much greater than for metal thiocyanate complexes. If free cyanide is absent, then metal thiocyanate complexes will form. Many of metal thiocyanate complexes found in ore processing solutions are insoluble. This process may play a role in removing some cyanide and metals from solution.

Sorption

Sorption of free cyanide, as well as complexed cyanides, to clays (Cruz et al, 1974; Schenk and Wilke, 1984), soils (Alesii and Fuller, 1976; Fuller, 1985), sludge (Raef et al, 1977a) and plant debris (Schenk and Wilke, 1984) occurs to a small extent.

Simple Cyanide Transformation and Degradation Process

The relative solubility of several simple cyanides is shown in Table B-2. The soluble compounds can readily release free cyanide, which may be subjected to the degradation processes described above. However, $Zn(CN)_2$, $CaCN$, $Ni(CN)_2$, and $AgCN$ are relatively insoluble in water.

Complex Cyanide Transformation and Degradation Processes

Solubilities of Complex Cyanides Salts

The solubilities of iron cyanide salts are listed in Table B-3. Most of these compounds are relatively insoluble. If an iron cyanide salt dissolves, the products are an alkali or heavy metal ion and either a ferrocyanide or ferricyanide complex, which are strong complexes. The dissociation of metal cyanide complexes such as ferrocyanide and ferricyanide is discussed below.

TABLE B-3

SOLUBILITIES OF FERROCYANIDE AND FERRICYANIDE SALTS

<u>Name</u>	<u>Formula</u>	<u>Solubility (g/l)^{a/}</u>
Ammonium Ferricyanide	$(\text{NH}_4)_3\text{Fe}(\text{CN})_6$	very soluble
Ammonium Ferrocyanide	$(\text{NH}_4)_4\text{Fe}(\text{CN})_6 \cdot 3\text{H}_2\text{O}$	soluble
Barium Ferrocyanide	$\text{Ba}_2\text{Fe}(\text{CN})_6 \cdot 6\text{H}_2\text{O}$	1.7 (15°C)
Cadmium Ferrocyanide	$\text{Cd}_2\text{Fe}(\text{CN})_6 \cdot x\text{H}_2\text{O}$	insoluble
Calcium Ferrocyanide	$\text{Ca}_2\text{Fe}(\text{CN})_6 \cdot 12\text{H}_2\text{O}$	868 (25°C)
Cobalt Ferricyanide	$\text{Co}_3(\text{Fe}(\text{CN})_6)_2$	insoluble
Cobalt Ferrocyanide	$\text{Co}_2\text{Fe}(\text{CN})_6 \cdot x\text{H}_2\text{O}$	insoluble
Copper (I) Ferricyanide	$\text{Cu}_3\text{Fe}(\text{CN})_6$	insoluble
Copper (II) Ferricyanide	$\text{Cu}_3(\text{Fe}(\text{CN})_6)_2 \cdot 14\text{H}_2\text{O}$	insoluble
Copper (II) Ferrocyanide	$\text{Cu}_2\text{Fe}(\text{CN})_6 \cdot x\text{H}_2\text{O}$	insoluble
Iron (II) Ferricyanide	$\text{Fe}_3(\text{Fe}(\text{CN})_6)_2$	insoluble
Iron (III) Ferricyanide	$\text{Fe Fe}(\text{CN})_6$	--
Iron (II) Ferrocyanide	$\text{Fe}_2 \text{Fe}(\text{CN})_6$	insoluble
Iron (III) Ferrocyanide	$\text{Fe}_4 (\text{Fe}(\text{CN})_6)_3$	2.5×10^{-4} b/
Lead Ferricyanide	$\text{Pb}_3 (\text{Fe}(\text{CN})_6)_2 \cdot 5\text{H}_2\text{O}$	slightly soluble
Magnesium Ferrocyanide	$\text{Mg}_2\text{Fe}(\text{CN})_6 \cdot 12\text{H}_2\text{O}$	330g
Manganese (II) Ferrocyanide	$\text{Mn}_2\text{Fe}(\text{CN})_6 \cdot 7\text{H}_2\text{O}$	insoluble
Nickel Ferrocyanide	$\text{Ni}_2\text{Fe}(\text{CN})_6 \cdot x\text{H}_2\text{O}$	insoluble
Potassium Ferricyanide	$\text{K}_3\text{Fe}(\text{CN})_6$	330 (4°C)
Potassium Ferrocyanide	$\text{K}_4\text{Fe}(\text{CN})_6 \cdot 3\text{H}_2\text{O}$	278 (12°C)
Silver Ferricyanide	$\text{Ag}_3\text{Fe}(\text{CN})_6$	0.00066 (20°C)
Silver Ferrocyanide	$\text{Ag}_4\text{Fe}(\text{CN})_6 \cdot \text{H}_2\text{O}$	insoluble

(Continued)

TABLE B-3 (Continued)

<u>Name</u>	<u>Formula</u>	<u>Solubility (g/l)^{a/}</u>
Sodium Ferricyanide	$\text{Na}_3\text{Fe}(\text{CN})_6 \cdot \text{H}_2\text{O}$	189 (0°C)
Sodium Ferrocyanide	$\text{Na}_4\text{Fe}(\text{CN})_6 \cdot 10\text{H}_2\text{O}$	318.5 (20°C)
Strontium Ferrocyanide	$\text{Sr}_2\text{Fe}(\text{CN})_6 \cdot 15\text{H}_2\text{O}$	500
Thallium Ferrocyanide	$\text{Tl}_4\text{Fe}(\text{CN})_6 \cdot 2\text{H}_2\text{O}$	3.7 (18°C)
Tin (II) Ferricyanide	$\text{Sn}_3 (\text{Fe}(\text{CN})_6)_2$	insoluble
Tin (II) Ferrocyanide	$\text{Sn}_2\text{Fe}(\text{CN})_6$	insoluble
Tin (IV) Ferrocyanide	$\text{SnFe}(\text{CN})_6$	insoluble
Zinc Ferrocyanide	$\text{Zn}_2 \text{Fe}(\text{CN})_6$	insoluble
Zinc Ferricyanide	$\text{Zn}_2 (\text{Fe}(\text{CN})_6)_2$	$2.6 \times 10^{-5\text{b/}}$
Zinc Ferrocyanide	$\text{Zn}_3 (\text{Fe}(\text{CN})_6)_2$	$2.2 \times 10^{-5\text{b/}}$

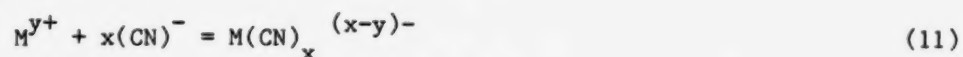
Source: Weast, 1969

a/ Source unless otherwise noted is from Weast , 1969.

b/ Source: Mezey and Neuendorf, 1981.

Dissociation of Metal Cyanide Complex Ions

A stability constant is a measure of the affinity or tightness of the binding of the complex between the cyanide radical and a metal. The reaction between a metal ion and cyanide to form a metal cyanide complex is



where M = metal with valence y; and

x = number of cyanide groups in the complex.

The stability constant or the inverse of the stability constant, the dissociation constant, is expressed as follows:

$$K_s = \frac{[M(CN)_x^{(x-y)-}]}{[M^{y+}][CN^x-]} = \frac{1}{K_d} \quad (12)$$

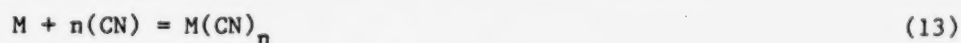
where K_s = stability constant;

K_d = dissociation constant; and

[] = concentration units in moles per liter.

The values for the stability constants for metal cyanide complex ions are shown in Table B-4.

In a solution containing different metals where more than one complex can form, a cumulative or gross constant, B_n , is used to describe the reactions between the metals and cyanide:



The cumulative constant, B_n , is expressed as follows:

$$B_n = \frac{[M(CN)_n]}{[M][CN]^n} \quad (14)$$

where the concentration units, [], are moles per liter.

The cumulative constant for specific metals can be quantified by the results of potentiometric titrations conducted both in the presence of and absence of the metal. Cumulative constants for individual metal ions are presented in Table B-5. The B_n values indicate the relative

TABLE B-4

STABILITY CONSTANTS OF METAL-CYANIDE COMPLEX IONS

COMPLEX ION	STABILITY CONSTANT ^{a/}
$\text{Cr}(\text{CN})_6^{3-}$	10^{33}
$\text{Cr}(\text{CN})_6^{4-}$	10^{21}
$\text{Fe}(\text{CN})_6^{4-}$	$10^{35.4}$
$\text{Fe}(\text{CN})_6^{4-}$	10^{47} b/
$\text{Co}(\text{CN})_6^{4-}$	10^{50}
$\text{Ni}(\text{CN})_4^{2-}$	10^{30}
$\text{Pd}(\text{CN})_4^{2-}$	10^{42}
$\text{Pt}(\text{CN})_4^{2-}$	10^{40}
$\text{Cu}(\text{CN})_2^-$	$10^{23.9}$
$\text{Cu}(\text{CN})_3^{2-}$	$10^{29.2}$
$\text{Cu}(\text{CN})_4^{2-}$	$10^{30.7}$
$\text{Ag}(\text{CN})_3^{2-}$	$10^{20.4}$
$\text{Ag}(\text{CN})_3^{2-}$	$10^{21.9}$
$\text{Au}(\text{CN})_2^-$	10^{37}
$\text{Au}(\text{CN})_4^-$	10^{85} (estimate)
$\text{Zn}(\text{CN})_4^{2-}$	10^{21}
$\text{Cd}(\text{CN})_4^{2-}$	10^{19}
$\text{Hg}(\text{CN})_4^{2-}$	10^{39}

a/ Source unless otherwise noted is from Sharpe, 1976.

b/ Source: Broderius, 1973.

TABLE B-5
CUMULATIVE CONSTANTS, B_n , FOR VARIOUS METALS
FOUND IN PRECIOUS METAL ORES

<u>Metal</u>	<u>Valence</u>	<u>a_n</u> ^{a/}	<u>Log (10)</u> <u>of B_n</u>	<u>Log (10)</u> <u>of [CN]</u>
Cadmium	+2	4	16.85	-1.6
Cobalt	+2	6	19.09	-1.5
Cobalt	+3	6	64	-9.0
Copper	+1	4	27.3	-4.3
Gold	+1	2	47.5	-18.6
Gold	+3	4	56	-11.4
Lead	+2	4	10.3	0
Mercury	+2	4	41.4	-7.8
Nickel	+2	4	31	-5.2
Silver	+1	4	21.1	-2.7
Zinc	+2	4	16.9	-1.7

a/ a_n = number of cyanide molecules in the metal-cyanide complex.

Source: Milligan, 1985b.

strength of the metal cyanide complex. To get an idea of how much cyanide in solution is needed to form a specific metal cyanide complex, Milligan (1985b) assumed a cyanide-metal complex to metal ratio equal to 2.0×10^{10} , and then solved for free cyanide content. Lead, for example, requires a free cyanide content of 1 mole per liter, while all other metals (Table B-5) would be dissolved and leached from the ore when mixed with smaller quantities of free cyanide. Certain minerals containing these metals in the ore may be more stable than the cyanide complex, and therefore the metal cyanide complex may not form.

The equations for cumulative constant or dissociation constant can be combined with the equation for dissociation of hydrogen cyanide to calculate equilibrium hydrogen cyanide concentration at given pH values and initial concentrations of the metal complex. A decrease in pH accelerates the reaction as does a decrease of initial concentration.

The rate of dissociation of metal cyanide complexes is also an important factor. The dissociation of a synthetic solution of single metal cyanide complexes (Cu, Zn, Ni, and Fe) was studied by Simovic et al. (1985). The test solutions (initially 200 mg/l total cyanide) were aerated, illuminated with ultraviolet light, and maintained at pH 7 (phosphate buffer). There was an initial rapid decrease in the total cyanide concentrations within the first 48 to 72 hours, which was attributed to volatilization of hydrogen cyanide. The total cyanide concentration continued to decline, but at a slower rate. The metal cyanide complex decay coefficient was determined for the two different temperatures tested (Table B-6). The half life for each metal cyanide complex was calculated from this data. Zinc cyanide complex had the fastest decay rate, followed by copper, iron, and nickel complexes. Only the decay rate of iron cyanide complex was affected by ultraviolet light (which is discussed in the next section). Other data from these studies, showed that residual total cyanide concentrations decreased to less than 1 mg/l within four days for the zinc cyanide complex solution and within 12 days for the copper cyanide complex solution (Simovic and

TABLE B-6
DEGRADATION OF METAL CYANIDE COMPLEXES IN
PHOSPHATE BUFFER AT pH 7^{a/}

	$k_1 \times 10^2$ (4 °C) (hr ⁻¹)	$t_{1/2}^{b/}$ (4 °C) (days)	$k_1 \times 10^2$ (20 °C) (hr ⁻¹)	$t_{1/2}^{b/}$ (20 °C) (days)
Zn(CN) ₄ ²⁻	1.78	1.6	4.49	0.64
Cu(CN) ₃ ²⁻	0.29	9.9	0.75	3.8
Fe(CN) ₆ ³⁻	0.14	20.6	0.47	6.1
Ni(CN) ₄ ²⁻	0.04	72.1	0.09	32.0

a/ Initial concentration is 200 mg/l. Adapted and modified from Simovic et al., 1985.

b/ Half-lives were calculated from the rate constants (Versar Inc., 1986).

Snodgrass, 1985). The total cyanide concentration of the iron cyanide complex solution was 10 mg/l after 15 days. The decay rate of the nickel cyanide complex solution was so slow that the concentration had not decreased to less than 30 mg/l even after nine days.

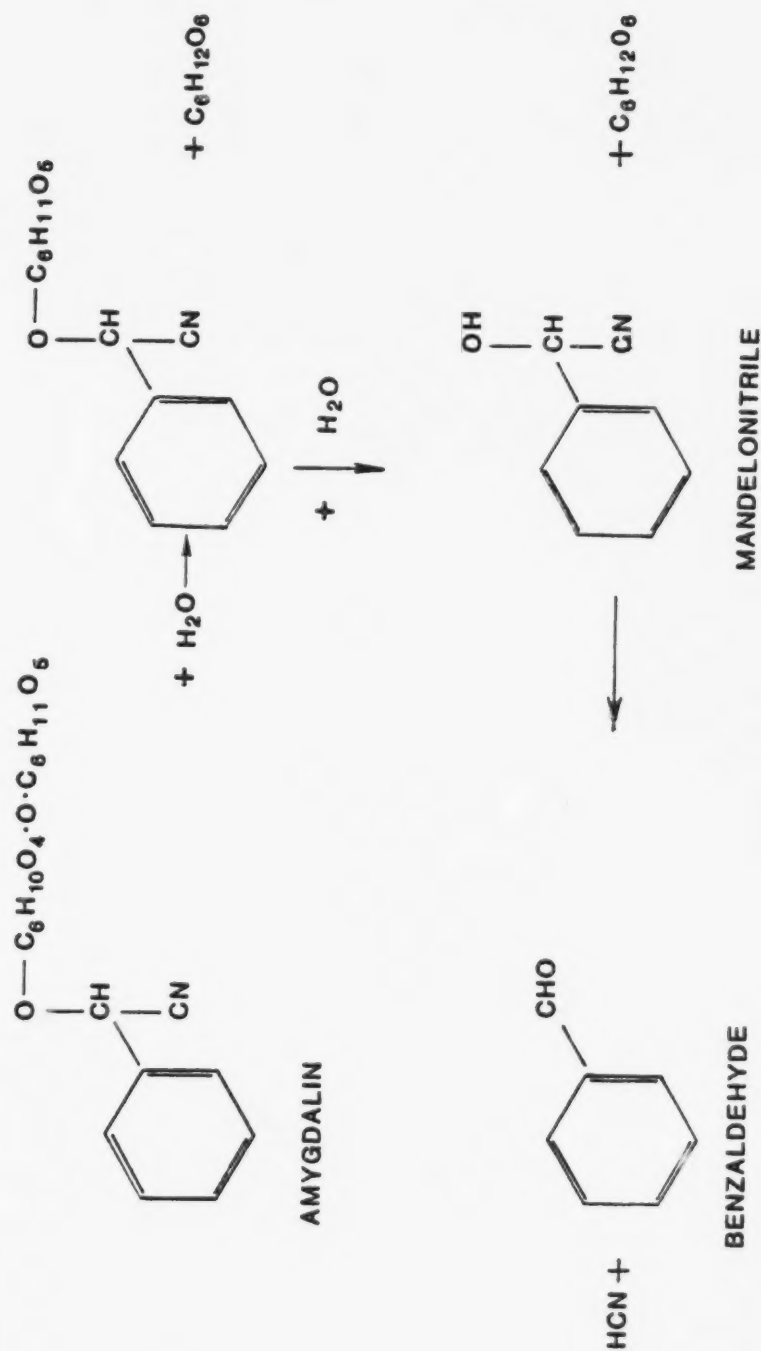
Photochemical Degradation

The iron cyanide complexes, $\text{Fe}(\text{CN})_6^{4-}$ and $\text{Fe}(\text{CN})_6^{3-}$, in water produce free HCN from photochemical degradation by sunlight (Broderius and Smith, 1980). The lower the concentration of the iron complex ions, the faster the rate of photodegradation. The amount of HCN formed will increase with increasing concentration of the photolabile iron cyanide. The maximum amount of total cyanide (complexed cyanide) converted to free cyanide was 85 percent and 49 percent for $\text{Fe}(\text{CN})_6^{4-}$ and $\text{Fe}(\text{CN})_6^{3-}$, respectively. Photodegradation rates decrease rapidly with depth in natural water systems. The ultraviolet radiation from the midday sun on a Minnesota lake during summer accelerated the decomposition of ferricyanide to a resultant half life of 20 minutes (Broderius, 1973). During the fall the half-life increased to 50 minutes. Simovic et al. (1985) research with degradation of metal cyanide solutions showed that of the variables, temperature, aeration, and presence of ultraviolet light, ultraviolet light had the largest effect on the iron cyanide solution. The results of tests by both Moggi et al. (1966) and Kelada et al. (1985) showed that cobalt III cyanide complex also is broken down by ultraviolet radiation.

Cyanogenic Glycosides Transformation and Degradation Processes

Cyanide may be released from cyanogenic glycosides subjected to hydrolysis in vitro by dilute mineral acids or in vivo by enzymes. One of the best known cyanogenic glycosides, amygdalin, occurs in the Rosaceae (rose) family. The hydrolysis of amygdalin is shown in Figure B-2. The HCN released from cyanogenic glycosides may undergo any of transformation or degradation processes described above for free cyanide.

FIGURE B - 2
THE HYDROLYSIS OF A CYANOGENIC GLYCOSIDE, AMYGDALIN



(MODIFIED FROM FULLER, 1985)

Mobility of Cyanide in Surface Water

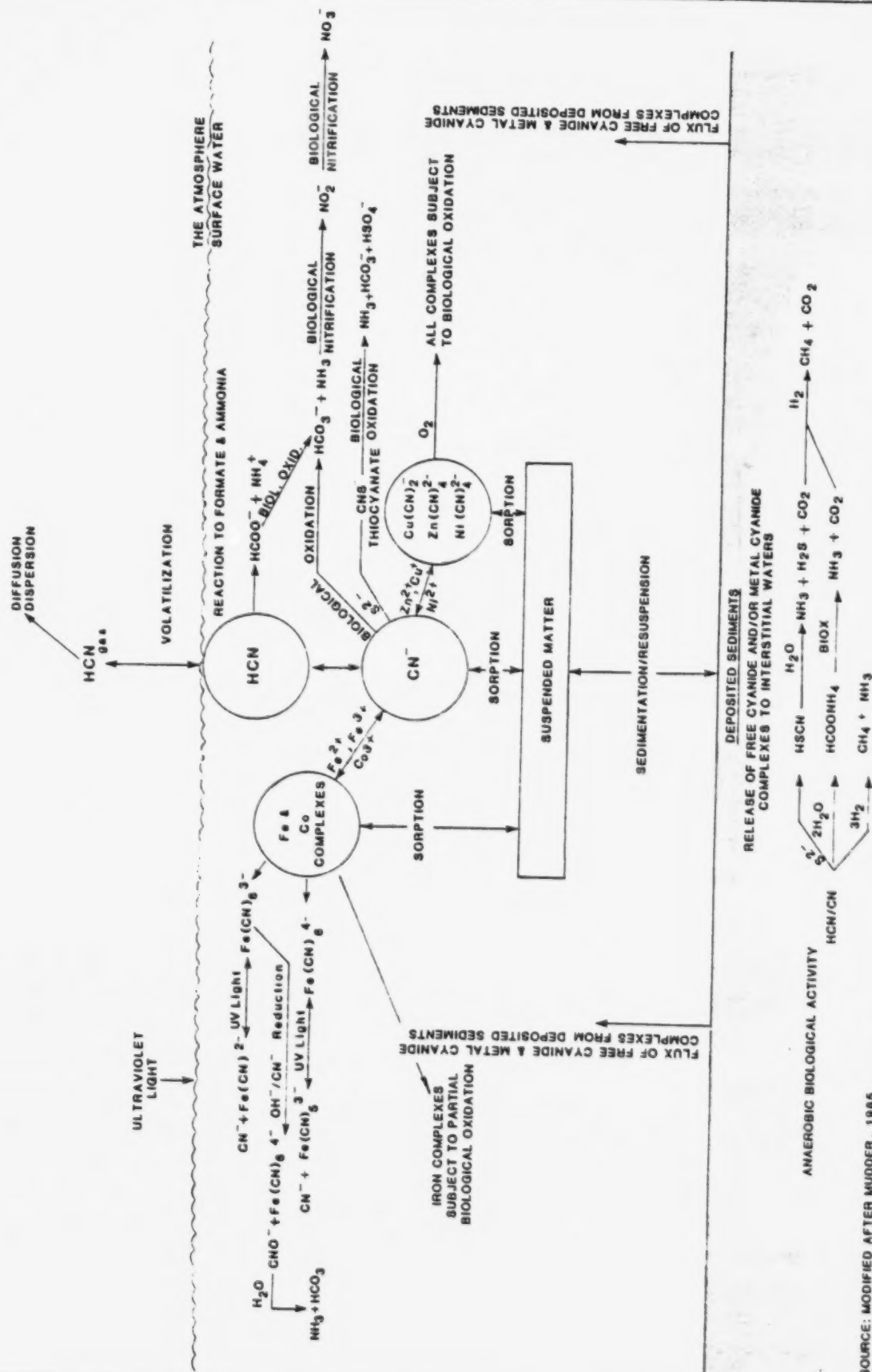
Figure B-3 summarizes cyanide reactions in surface water. The mobility of cyanide in surface water will be dependent on a large number of factors, including pH, temperature, concentration and type of metals and resulting metal cyanide complexes, properties of the water body (depth, surface area, amount of turbulence or aeration), presence of ultraviolet light, and quantities and forms of transported organic and inorganic suspended matter, and interchange with sediment. The different mechanisms for cyanide degradation have been discussed above; each location will have its own set of factors which may tend to release or immobilize cyanide. Generally, free cyanide ion will be more mobile in waters with higher pH, lower temperature, lower levels of metals, organic and inorganic suspended matter, and little interaction with sediment. The properties of a water body that would promote higher mobility of cyanide are stagnant, deep conditions with little surface area. Cyanide will more readily volatilize in highly aerated waters with lower pH's. Free cyanide will be less mobile in waters where there are higher concentrations of metals, sulfide, and organic and inorganic matter. If iron or cobalt complexes are present, then the presence of ultraviolet light may be a factor in increasing the mobility of cyanide.

No predictive models have been developed for the mobility of cyanide in streams. However, several models have been developed to predict the natural degradation of cyanide in gold mining effluents (refer to the section, Degradation of Cyanide at Heap leach Operations).

Mobility of Cyanide in Ground Water

The mobility of cyanide in ground water is also dependent on many factors such as pH, temperature, concentration and type of metals present and subsequent formation of metal cyanide complexes, amount of aeration, and interaction with soil or rock particles. Volatilization rates of HCN from ground water are probably reduced compared to surface water. Volatilization, however, may be an important process in the

FIGURE B-3
CYANIDE REACTIONS IN SURFACE WATER



SOURCE: MODIFIED AFTER MUDDER, 1985

vadose zone. Several researchers have showed that stripping coefficients for stagnant cyanide solutions were greatly reduced compared to agitated solutions, since the process becomes dependent on molecular diffusion. On the other hand, processes that tend to tie up cyanide such as sorption and complexation may be more important processes for ground water than surface water. Ground water flow is generally much slower than surface water which allows more time for interaction of the water with soil or rock minerals. Reaction of cyanide to ammonia and formate ions may also be an important process to remove cyanide from ground water. The other factors such as pH and temperature are also important and vary in the same way as for surface water; that is cyanide is more mobile at higher pH values and lower temperatures. Iron and cobalt cyanide complexes will not undergo photochemical degradation in ground water; however, if ground water is discharged to surface water this process may become important.

Mobility of Cyanide in Soils

The mobility of cyanide in soils is largely dependent on soil clay content, depth of soil, content of hydrous oxides of iron, manganese, aluminum and other metals, pH, presence of aerobic or anaerobic conditions, and presence of soil organic matter (Fuller, 1985). Alesii and Fuller (1976) and Fuller (1985) found cyanide in water as $\text{Fe}(\text{CN})_6^{3-}$ and CN^- to be very mobile in soils, whereas cyanide as KCN in natural landfill leachate (which contained metals) was less mobile in soils. During this experiment, the anaerobic state of the soil columns inhibited microbial degradation of cyanide. The limit for effective anaerobic degradation of cyanide was found to be 2 mg/l in studies of a sewage wastestream (Coburn, 1949), which is considerably lower than 100 mg/l used in the experiment. The high clay content soil retained more ferricyanide than the sandier soil of similar pH. Ferricyanide was retained the most in soils having a low pH, which was explained by the clay surface having a high percentage of positive exchange sites. The KCN solution leached most rapidly in the soil having the lowest pH.

Cyanide was retained most by soils having a high concentration of hydrous oxides. Mobility of cyanides is greatest in soil at high pH and low clay content.

Cyanide-yielding compounds rapidly ammonify and nitrify in the same soils under aerobic field conditions (Fuller, 1985). In fact, despite regular use of pesticides and fertilizers containing low levels of cyanides or cyanide-yielding compounds, cyanides do not accumulate in the soil.

Wharf Resources Inc. (1982) conducted tests of effluent from cyanide solutions applied to soil columns containing native soil from the Annie Creek Mine area in the Black Hills, South Dakota (Table B-7). Results from the 150 mg/l total cyanide solution showed that both total and free cyanide were reduced to less than half the concentration of the originally applied solutions during the test and continued to decline over the next 6 weeks.

Research is being conducted by DuPont on soil collected from below heap leach pads at two mining operations (F. DeVries, Dupont Company, personal communication, 1986). Besides describing soil mineralogy, they are conducting two types of tests including 1) stirred reaction with cyanide, and 2) column tests with cyanide. Data from these tests will be incorporated into a model used to predict the mobility of cyanide in soils.

CYANIDE CHEMISTRY OF HEAP LEACH OPERATIONS

Cyanidation

In the cyanidation process, precious metals are leached from ores with a cyanide solution. In most mineral leaching operations in the United States, the leaching solution is prepared from sodium cyanide. The sodium cyanide in solution will dissociate to sodium and cyanide ion as discussed above (equation 3). The optimum pH process solution for leaching purposes is 10.3 (Barsky et al., 1962), so cyanide ion remains predominant (refer to Figure B-1). The leaching solution contains sodium cyanide at a concentration of 0.05 percent (equivalent

TABLE B-7

RESULTS OF TESTS WITH CYANIDE SOLUTIONS (in mg/l) ADDED TO
COLUMNS CONTAINING NATIVE SOIL FROM THE AREA OF ANNIE CREEK MINE, SD^{a/}

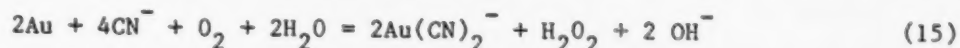
Test Conditions	Test 4-SS (Nominally 150 mg/l)			Test 5-SS (Nominally 1 mg/l)		
	Date	Free CN	Total CN	Date	Free CN	Total CN
Influent solution	8/16 - 8/19/82	36.5	149	8/25 - 8/27/82	1.0	1.0
Effluent	8/17	4.5	65	8/26	<0.01	0.03
Effluent	8/18	17	46.5	8/27	<0.01	<0.01
Effluent following fresh-water flush	10/4	2.4	29	10/4	<0.05	<0.05

Source: Wharf Resources Inc., 1982.

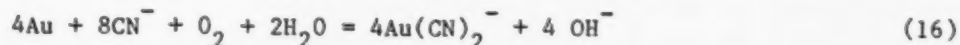
a/ Cyanide solutions added to soil columns at about 20 l/min/m² (0.5 gal/min/ft²) for 3 days.

to about 250 mg/l free cyanide) Chamberlain and Pojar (1984). At some operations, the cyanide concentration is much higher (600 to 1000 mg/l) for the first few days of leaching and subsequently drops to approximately 200 mg/l. The rate of dissolution depends on cyanide concentration, oxygen availability, temperature and solution pH. The efficiency of leaching depends on the type of ore. Ore that contains clean, free fine-sized gold particles, little clay content, and no cyanide impurities that may destroy cyanide or inhibit its reaction provides the most efficient leaching situation. Since the reaction is temperature sensitive, the leaching rate of precious metals during colder conditions may be only 70 percent of the leaching rate during summer operating conditions (Milligan, 1985b). Examples of cyanicides are sulfide and ferrous or ferric iron. Details of two example cyanide leaching operations are provided in Appendix A.

The reaction for dissolution of gold and complexation with cyanide is (Heinen et al., 1978):



A lesser amount of gold is solubilized as shown in the Elsner's equation:

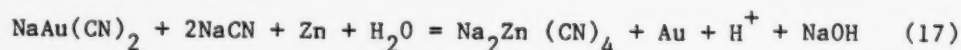


The equations for silver dissolution are similar.

Other metal cyanide complexes may be present in the leaching solution depending on the various metals and their forms in the ore. If the metals in the ore are in the form of compounds less stable than the cyanide complex and the metals are exposed to the leaching solution, then the rate of metal dissolution by cyanide increases directly in proportion to the free cyanide concentration present in the solution. Eventually, a limit is reached at the maximum dissolution rate of the metal cyanide complex; further increases in the free cyanide concentration may have a slight retarding effect on the dissolution rate of the complex (Milligan, 1985b).

The pregnant solution (process solution containing complexed precious metals) is processed through carbon adsorption columns and/or zinc precipitation units in order to recover the gold and silver. In the carbon process the metal cyanide complexes adsorb to the carbon surface. When the carbon columns reach a certain loading capacity, the metals are stripped from the carbon with an alcohol-caustic-cyanide solution. The gold and silver from this solution is removed by electrowinning.

Alternatively, zinc dust is added to the pregnant solution to precipitate the gold and silver cyanide complexes in the zinc precipitation process. Gold and silver precipitation are improved by adding lead acetate or lead nitrate to the solution. The precipitation reaction for gold is:



The solution containing the precipitate is filtered and dried for smelting.

Cyanide in Spent Leach Piles

Very little data exists on the amounts and forms of cyanide in spent leach piles. It is difficult to compare the limited data that exists since researchers are not using a standardized method of sampling the spent ore heaps or leaching the solid sample before analysis. The cyanide content and forms in spent leach piles will depend on the ore mineralogy, ore pH, heap permeability, the thickness of the heap, cyanide concentration in process solution, solubility and dissociation rate of metal cyanide complexes, temperature, the type and application of rinsing solutions, and the rate of release of cyanide from the pile. Volatilization is probably the most important process for the removal of cyanide from spent ore heaps after the heaps have been rinsed. Atmospheric sampling data are not available for the low level release of HCN from spent leach piles.

Research is currently being conducted by J. Hendrix (University of Nevada, personal communication, 1986) on cyanide in spent leach piles. His research consists of 1) experimentation with a leaching column containing ore in the laboratory and 2) collection of samples (representative sampling on a grid) from spent leach piles. Dr. Hendrix is also developing analytical methods to determine the amounts of specific metal cyanide complexes present.

Engelhardt (1985) and Milligan (1985a) studied the decay of cyanide after the heap leaching of some tailings (15 percent plus-100 mesh) that were formerly processed for lead, zinc, and silver (sulfide and oxide circuit) in the 1940's and 1950's. The location of this operation was in a desert area. Approximately 5,400 kilograms (12,000 pounds) or 11.5 percent of the cyanide remained in the spent heaps, after rinsing the 76,000 metric tons (84,000 short tons) of ore. A time-series study was initiated to examine the natural dissipation of cyanide levels in the ore. Samples were collected from 11 areas on the heap by driving a 3.8 centimeters (1.5 inch) pipe through the heap to the pad. Samples were agitated for one hour with distilled water and the slurry was filtered to recover the solution. After adjusting the pH to 12.0, the samples were analyzed for free cyanide. Sampling was conducted in January (3 months after the leaching process ceased), March, June, and September, 1983 and 6 months later in March, 1984. The pH in the heaps fell from 10.5 at the cessation of the operation to approximately 9 in late 1984. Results showing substantial decreases in free cyanide concentrations between the initial and final sampling periods are presented in Table B-8. Total cyanide data was not reported but it is stated that total cyanide was almost the same as free cyanide implying that there are no significant amounts of complexes. The data showed little correlation of cyanide concentration with depth. Based on these data (relatively few data points), the authors stated that at the present rate of degradation, it would take approximately four years for the cyanide concentration of the spent heap pile to decay to 1 mg/kg.

TABLE B-8

FREE CYANIDE CONCENTRATIONS IN ELEVEN
LOCATIONS IN THE DARWIN HEAP

Darwin ID No.	Heap No.	Percent Moisture		Free Cyanide (mg/kg)		Percent Loss of Free Cyanide During 15 Months
		Jan 83	Mar 84	Jan 83	Jan 84	
Q3S2	1	14.6	14.6	102.6	<6.8	93.4
Q3S3	2	14.0	13.0	118.8	13.4	88.7
Q3S4	3	16.4	15.5	196.2	23.8	87.9
Q6S1	4	14.7	14.6	144.8	22.2	84.7
Q6S2	5	14.6	12.5	87.2	20.0	77.1
Q6S3	6	15.9	14.3	155.0	28.4	81.7
Q6S4	7	15.2	12.0	91.4	<6.8	92.6
Q9S1	8	14.3	12.2	146.8	37.5	74.5
Q9S2	9	14.8	11.9	34.7	<6.8	80.4
Q9S3	10	14.5	11.8	8.5	<6.8	21.2
Q9S4	11	13.4	11.4	7.7	<6.8	16.9

Source: Engelhardt, 1985; Milligan, 1985a.

Research on the destruction of cyanide in the leached heaps was conducted at the Stibnite Mine in Idaho (Stotts, 1985). After leaching was completed, a solution containing chlorine and lime was sprayed on the heaps. The effluent from the rinsing was recycled through the neutralization system until it contained a free cyanide concentration of 0.2 mg/l. After a 0.2 mg/l concentration was reached, hourly testing of the solution was done over a period of 24 hours. If the 24 hour average free cyanide concentration did not exceed 0.2 mg/l and no single sample exceeded 1.0 mg/l, then the heap was environmentally suitable for disposal as required by the operator's agreement with the U.S. Forest Service. If, however, the 24 hour test failed to meet these requirements, the entire procedure was repeated. An analysis for a sample from the chlorine pond (rinsing solution) is given in Table B-9. This table shows the metals associated with the ore at Stibnite, some of which may form salts of metal cyanide complexes and remain in the spent ore. After treatment with chlorine, the spent ore was hauled to an old tailings site and spread out in thin layered lifts of 0.3 to 0.6 meters (1 to 2 feet).

Ten locations in the spent ore were sampled at 15 to 30 centimeters (6 to 12 inches) below the surface at one, five, and ten day intervals. Cyanide was analyzed from the leachate produced from the mixing of 25 grams of ore placed in 50 milliliters of cyanide-free caustic soda (NaOH) solution at 20 percent strength. The ore was leached for 12 to 24 hours. Results of the time series decay of cyanide for eight of the samples are shown in Figure B-4. The average 10-day decrease was approximately 50 percent of the content on the first day, with a range from about 10 percent for the samples with a very low starting concentration to a high of nearly 80 percent for samples having a higher starting concentration.

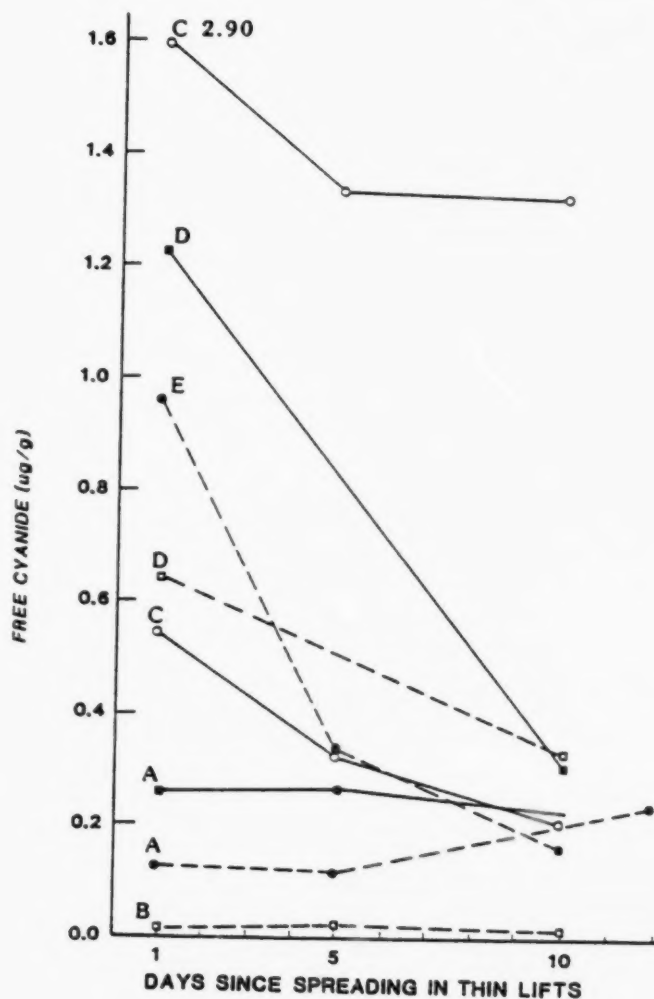
Ray (1985) sampled various heap leach piles in the southeastern desert of California and found that total cyanide levels were highly dependent upon the mineral composition of the ore (Table B-10). The sampling procedure was not described. The total cyanide analysis was conducted on a 20 gram sample that was subjected to a 24-hour leaching

TABLE B-9
SOLUTION SAMPLE OF CHLORINE POND AT STIBNITE MINE, IDAHO
August 24, 1983

Chloride	1,724 mg/l
Arsenic	0.271 mg/l
Antimony	0.021 mg/l
Calcium	560 mg/l
Copper	0.071 mg/l
Iron	0.590 mg/l
Lead	0.034 mg/l
Mercury	0.357 mg/l
Sodium	135 mg/l
Zinc	0.030 mg/l
Cadmium	0.016 mg/l

Source: Stotts, 1985.

FIGURE B-4
CYANIDE DEGRADATION IN TREATED WASTE
ORE FROM STIBNITE MINE, IDAHO



NOTE: THE LETTERS (A to E) REPRESENT LOCATIONS. TWO SAMPLES WERE TAKEN FROM SEVERAL LOCATIONS (A, C, AND D). THE SOLID AND DASHED LINES ARE FOR CLARITY.

(MODIFIED FROM STOTTS, 1985)

TABLE B-10
TOTAL CYANIDE CONCENTRATIONS FOR VARIOUS
HEAP LEACH OPERATIONS IN CALIFORNIA

<u>Description of Ore Samples</u>	<u>Run No.</u>	<u>mg/kg</u>
Samples low in iron	1	0.97
	2	0.41
	3	0.24
	4	0.42
	5	0.12
	6	0.27
	7	1.5
	8	0.90
Samples high in iron and copper	9	75
	10	34
	11	9.0
Samples high in iron, mined for silver	12	17.1
	13	5.9
	14	11.2
	15	105
Samples high in copper	16	41
	17	83
	18	91
	19	5.7
Samples low in cyanicides	20	0.82
	21	<0.05
	22	<0.05
	23	<0.05
	24	1.0
	25	0.07
	26	<0.05
	27	0.12
	28	0.20
	29	<0.05
	30	<0.05

Source: Ray, 1985.

in the dark using a 1.25 N NaOH solution, filtration, and analysis of the filtrate by the EPA (1979) distillation/destruction method, followed by colorimetric measurement.

The California Regional Water Quality Control Board, Colorado River Basin, Region 7 (1985) use to require a 1.0 mg/kg limit on the total cyanide found in abandoned heap leach piles. After reviewing the literature, specifically fish toxicity studies and cyanide environmental chemistry, they have changed the limit to 10 mg/kg. Their rationale is that because iron is the major metal atom available for complexation, iron cyanides are expected to be the only strong complexes formed. Other complexes are weaker and can be expected to degrade readily to cyanide ion. Therefore, the major species to consider in heap leach piles are iron cyanides and cyanide ion. Since iron cyanides are considered to be of low toxicity and have proven to be generally non-leachable, only cyanide ion content should be considered. A cyanide level of 0.02 mg/l was acceptable to the Regional Board and after multiplying by 100 (their usual practice when accounting for dilution in the environment), a level of 2.0 mg/l was obtained. The analysis of the sample is performed by leaching 1 part solid to 5 parts liquid; using this ratio and 2.0 mg/l, the acceptable limit for a solid is 10 mg/kg. Based on this rationale requirements from the Regional Board, the Mesquite Mine was required to rinse as follows when abandoning heap leach piles: 1) 90 percent of at least 10 samples shall contain less than 10 mg/l free cyanide and 2) none of the samples shall contain more than 20 mg/l free cyanide.

A sample collected from leached ore (with pH of 8.3) at the Zortman and Landusky heap in Montana had a concentration of 4.5 mg/kg for both total cyanide and cyanide amenable to chlorination (ERCO, 1984). The method of analysis was that prescribed by the EPA (1982). Concentrations of total cyanide and cyanide amenable to chlorination in the inactive heap leach material (with pH of 8.8) from the Pinson Mine in Nevada were both less than 2 mg/kg.

The sample extraction or leaching method prior to analysis may determine the content of cyanide in the sample. Spent heap leach wastes from Tombstone Silver Mines, Inc. (Arizona) were sampled and 75 grams of sample were leached with 150 milliliters of water and 0.1 gram of lime (CaO) for 1 hour (Pahlman, 1986). Most of the values were less than 0.1 mg/l with a range of less than detectable to 0.40 mg/l. An assay method from the U.S. Bureau of Mines, in which extraction was allowed for 12 hours on 40 gram of sample with 200 milliliters of water and 1 gram of sodium hydroxide, gave cyanide values that were 2 to 10 times greater than the previous method. The range of cyanide concentrations was less than 0.25 to 0.86 mg/kg with more than half the values below the detection limit of 0.25 mg/kg.

Sampling was conducted of the runoff from test heaps at the Annie Creek Mine (South Dakota) that were neutralized with hypochlorite followed by water (McGrew, 1985). After the first month (1982) there was more than a 10-fold decrease in both total cyanide and weak acid dissociable cyanide with decreases of 300 to 3.4 mg/l and 300 to 10 mg/l, respectively. Values continued to decrease with a range of 0.2 to 0.01 mg/l weak acid dissociable cyanide for sampling in December, 1983 to June, 1985. The test heaps were also sampled with depth up to 1.8 meters (6 feet). Of a total of 30 samples analyzed for total cyanide at 0.3 meter (1 foot) intervals, 21 samples were less than the detection limit of 0.5 mg/l, five analyses were between 0.5 and 0.6 mg/l, three between 0.6 and 0.7 mg/l, and one was higher than 0.7 mg/l. Of the 30 samples, for weak acid dissociable cyanide, 28 were below the detection limit of 0.5 mg/l and 2 were between 0.5 and 0.6 mg/l. Samples were also taken of the clay liner directly below the heaps. Cyanide did not penetrate below a depth of 10 centimeters (4 inches) based on 23 samples analyzed at 5-centimeter (2-inch) depth intervals. Of the 23 total cyanide concentrations, only 5 had detectable levels which ranged from 1.29 to 2.92 mg/l in the 0- to 5-centimeter (0- to 2-inch) and 5- to 10-centimeter (2- to 4-inch) clay samples. Weak acid dissociable cyanide was detected in only one sample at 0.83 ppm in a 5 to 10 centimeter (2- to 4-inch) interval.

There also is little information on the content and forms of cyanide in leachate from spent heap leach piles. As a part of the study by Engelhardt (1985) and Milligan (1985a) described above, the entrained solution in the heaps was also sampled for cyanide content. The moisture content in the first sampling (January, 1983) ranged from 13.5 to 16.4 percent and the final sampling (March, 1984) ranged from 11.4 to 15.5 percent. The average values for the two sampling periods were 340 mg/l and 106 mg/l free cyanide, respectively.

Degradation of Cyanide at Heap leach Operations

During the course of operation and at closure, cyanide in spent ore piles and process solutions must be rendered harmless. There has been very little published on the treatment of cyanides in spent ore piles, while extensive literature exists on the treatment processes for solutions containing cyanide.

Spent Leach Heap Piles

Upon closure of spent heaps operators are using several different methods to expedite the destruction of cyanide in the heaps. The requirements for neutralization vary by state (Table B-11). Generally, the rinsing procedure consists of either applying fresh water or an alkaline solution containing chlorine to the heap. The resulting effluent is recycled through the heap after the rinseate is treated with a method to destroy cyanide. This process is repeated until the cyanide concentration required in the effluent is obtained. Methods for neutralizing cyanide in water are described in detail below. Examples of the amounts of cyanide remaining in spent piles after rinsing were discussed above.

Natural degradation processes including volatilization, photo-decomposition, oxidation, adsorption, and biodegradation continue to reduce levels of cyanide in the spent heaps after rinsing. Examples of some rates of cyanide degradation in spent heaps were discussed above.

TABLE B-11

WESTERN STATE REGULATIONS OR GUIDELINES FOR NEUTRALIZATION
OF SPENT HEAP LEACH PILES

<u>State</u>	<u>Required Cyanide Content of Rinseate</u>
Arizona	Require the operators to show evidence there is no free cyanide; no recommendations for rinsing process (J. McCutchan, Arizona State Mine Inspector, personal communication, 1986).
California	Guidelines vary between Regional Boards. Region 5 - 0.35 mg/l free cyanide (D. Heiman, California Regional Quality Control Board - Region 5, personal communication, 1986). Region 6 - 0.2 mg/l free cyanide or 10 mg/kg total cyanide (M. Watkins, California Regional Water Quality Control Board - Region 6, personal communication, 1986). Region 7 - 2.0 mg/l or 10 mg/kg free cyanide (California Regional Water Quality Control Board, 1985).
Colorado	Considering developing guidelines. Recommend 2 mg/l free cyanide; in sensitive areas recommend 0.75 mg/l. Recommend fresh water or hydrogen peroxide for rinsing method (A. Baldridge, Colorado Mined Land Reclamation Division, personal communication, 1986).
Idaho	Developing regulations (I. Nautch, Idaho Water Quality Bureau, personal communication, 1986). Requirements for Stibnite (0.2 mg/l free cyanide); recommend hypochlorite rinse.
Montana	Developing regulations/guidelines (D. Smith, Montana Department of State Lands, personal communication, 1986).
New Mexico	Guidelines; 45 kg (100 lb) sample rinsed can not have more than 100 mg/l total cyanide (A. Die, New Mexico Environmental Improvement Division, personal communication, 1986).
Nevada	Required to rinse with water until pH of rinse water is 8.5 for three consecutive days (H. Van Drieun, Nevada Division of Environmental Protection, personal communication, 1986).

(Continued)

TABLE B-11 (Continued)

<u>State</u>	<u>Required Cyanide Content of Rinseate</u>
Oregon	Guidelines of 0.01 mg/l total cyanide; recommend hypochlorite rinse (K. Ashbaker, Oregon Department of Environmental Quality, personal communication, 1986).
South Dakota	Guidelines for Wharf Resources (0.75 mg/l total cyanide); currently working on rinsing method recommendation (B. Townsend, South Dakota Department of Natural Resources, personal communication, 1986).
Utah	Guidelines for Mercur Mine (5 mg/l free cyanide); no recommendations for rinsing method (C. Dietz, Utah Water Pollution Control, personal communication, 1986).
Washington	Developing regulations/guidelines (B. Lingley, Washington Department of Natural Resources, personal communication, 1986).
Wyoming	No regulations or guidelines (C. Bosco, Wyoming Land Quality Division, personal communication, 1986).

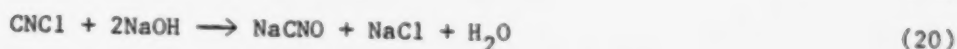
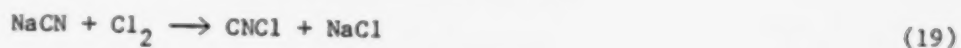
Process Cyanide Solutions

Barren solution should be subject to cyanide destruction upon closure. In addition, during fall some barren solution may need to be treated and released (possibly as a land application) in anticipation of winter precipitation to meet water balance requirements. The rinsing solution used to neutralize the spent ore heaps will also require a treatment process. The methods described below are based on volatilization (natural degradation), oxidation (alkaline chlorination, hydrogen peroxide, Inco process), and biological processes. The major treatment processes that are used or may be used at leaching operations are summarized here; these and other processes are described in more detail in Huiatt et al. (1983) and Scott (1985).

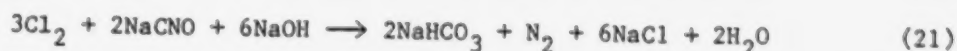
Natural Degradation. The results of studies of barren and tailings ponds in Canada (Simovic et al., 1985; Schmidt et al., 1981) show that natural degradation of cyanide occurs with over 90 percent of cyanide decrease attributed to volatilization of molecular HCN. For example, the cyanide content of a waste barren pond decreased from 64 mg/l in March to 0.05 mg/l in the following August and the pH dropped from 10.5 to 7.0 (Schmidt et al., 1981). The pH drop was a result of natural carbonation and the hydrolysis of thiocyanate. Some photodecomposition of ferrocyanides occurred.

A model has been developed to predict the natural degradation of cyanide in gold mill effluents, specifically barren solution and tailings pond water (Simovic et al., 1985; Simovic and Snodgrass, 1985). The model utilized the results from the synthetic solutions described in the section, Dissociation of Metal Cyanide Complex Ions, and assumed that the decay rate of a metal cyanide complex and subsequent volatilization of HCN control the disappearance of total cyanide from solution, with metal cyanide complex decay being the rate controlling factor. The model was used to predict degradation times for representative wastewater systems at two Canadian gold mills. The degradation of cyanide from tailings pond water was predicted very closely, but the model needs further calibration for the barren solutions.

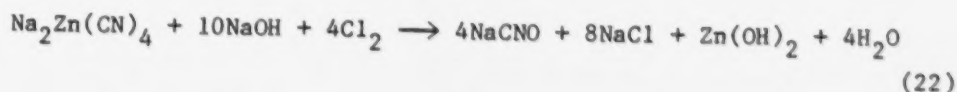
Alkaline Chlorination. The most developed of all the available methods in regards to background experience, operational simplicity, control techniques, availability of equipment, and engineering expertise, is alkaline chlorination (Ingles and Scott, 1981). The complete oxidation of cyanide to nitrogen and bicarbonate requires two stages (Scott, 1985). In the first stage cyanide undergoes oxidation and hydrolysis at a minimum pH of 10.5 as shown:



During the second stage of the process, cyanate is further oxidized to nitrogen and bicarbonate at a pH of about 8.5, which can be represented by the overall reaction:



Metal cyanide complexes are oxidized during the first stage of the process as shown for the zinc cyanide complex:



The alkaline chlorination method destroys free cyanide ion, hydrogen cyanide, and cyanide from most metal cyanide complexes with the exception of iron cyanide complexes. Table B-12 presents the advantages and disadvantages of alkaline chlorination.

Hydrogen Peroxide. The hydrogen peroxide method, which is well known and widely used in the treatment of effluents from the steel hardening and other industries, is now being applied to the gold mining industry. The hydrogen peroxide method is favorable from the environmental view since no toxic by-products are generated nor are additional chemicals added which may be detrimental to the environment (Knorre and Griffiths, 1985). In addition, metals are precipitated as hydroxides. The reaction for the oxidation of cyanide to cyanate is:

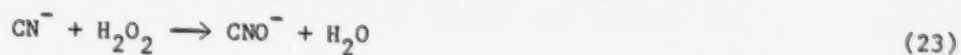


TABLE B-12

ADVANTAGES AND DISADVANTAGES OF ALKALINE CHLORINATION

ADVANTAGES OF ALKALINE CHLORINATION

- 1) Very widely-used method, expertise is available.
- 2) Influent to process already basic.
- 3) Reactions complete and reasonably rapid.
- 4) Toxic metals removed.
- 5) Chlorine readily available in several different forms.
- 6) Readily adaptable to either continuous or batch operation.
- 7) Capital outlay relatively low.
- 8) Good fail-safe control.
- 9) Easily controlled to first stage of oxidation, if disposal of CNO^- is permitted.

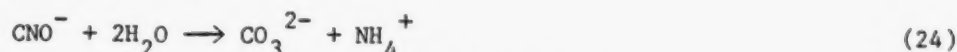
DISADVANTAGES OF ALKALINE CHLORINATION

- 1) Reagent costs are high, particularly if complete oxidation is required. Thiocyanate, thio-salts and ammonia are additional heavy consumers of chlorine.
- 2) Requires careful control of pH to prevent formation of cyanogen chloride which is very toxic.
- 3) Cyanide is not recovered.
- 4) Hexacyanoferrates are not usually decomposed.
- 5) Metal content is not recovered.
- 6) The chloride content of the effluent is increased in direct proportion to the amount of chlorine added.
- 7) There is a possibility of forming toxic chlorine derivatives (e.g. chlorinated organic compounds) which will require further treatment.
- 8) Residual excess chlorine can be toxic to aquatic species.^{a/}

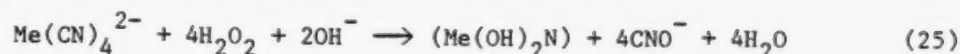
a/ Clean-up of excess chlorine is readily accomplished with $\text{S}_2\text{O}_3^{2-}$ or H_2O_2 , but an extra step is needed.

Source: Adapted from Ritcey and McNamara, 1978; cited by Ingles and Scott, 1981.

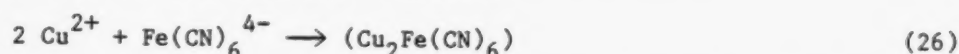
The cyanate formed in this reaction hydrolyzes further to form ammonium and carbonate ions:



The reaction for the precipitation of metals is:

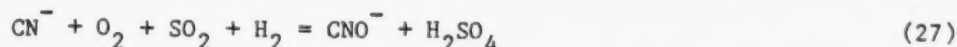


Complex iron cyanides are too stable to be oxidized but they may be precipitated by the addition of copper:



The hydrogen peroxide method destroys hydrogen cyanide, cyanide ion, and cyanide in copper, zinc, and nickel cyanide complexes. If copper is added, iron cyanide complexes may be precipitated.

Inco Process. This method was originally developed for base metal mining operations, but is now used by a number of gold mines in Canada. Oxidation by SO_2 in air in the presence of a copper catalyst causes the rapid removal of cyanide and metal cyanide complexes. The overall reaction is the oxidation of cyanide to cyanate which is described by the equation:



Iron cyanide complexes are removed by precipitation as copper or zinc ferrocyanides. The metals except for iron are precipitated as metal hydroxides. Thiocyanate is not removed.

Biological Treatment. Homestake Mining Company has recently developed a biological treatment method for removing cyanide and metal ions from effluents (Mudder and Whitlock, 1983). An essential requirement for successful operation of this process is the ability to blend mine water at 21 to 29° C (70 to 85° F) with tailings impoundment water at 1.1 to 21° C (34 to 70° F) to maintain a year round combined wastewater temperature sufficiently warm at 10 to 18° C (50 to 65° F) to sustain effective biological process rates. The two stages of the the methods are 1) bacterial oxidation of cyanide and thiocyanate to carbon dioxide, sulfate, and ammonia concurrent with the adsorption of metals

by the bacteria and 2) bacterial nitrification of ammonia to nitrate. The only reagents added are soda ash as an inorganic carbon source to aid nitrification, and phosphorus as a trace nutrient. Total cyanide is reduced to 0.30 mg/l from an influent concentration of 2.0 mg/l; thiocyanate content is reduced to less than 0.10 mg/l from 50.0 mg/l. Metals are returned to the tailings pond.

Environmental Fate of Cyanide in Heap Leach Mining Wastes

The chemical and biological processes controlling the fate of cyanide in heap leach mining operations are summarized in Figure 20 (Chapter 4). These processes were discussed in detail in the section entitled, Environmental Fate of Cyanide. Heap leach mining wastes may contain free cyanide (HCN and CN^-), metal cyanide complexes, and salts of metal cyanide complexes. The process controlling the fate of free cyanide in these wastes is volatilization of HCN to the atmosphere. HCN will diffuse upward through the troposphere and is destroyed in the stratosphere (Singh et al., 1984). An important control on volatilization is pH; below a pH of 9, HCN is predominant over cyanide ion.

Metal cyanide complexes such as iron, copper, zinc, nickel, cobalt, and cadmium, which are the most common at gold and silver operations (Huiatt, 1985), decompose and release cyanide ion at varying rates. Zinc and cadmium complexes, the least stable complexes, readily decompose as free cyanide decreases during the rinsing process. Strong complexes such as iron cyanide complex may remain in the ore. Iron cyanide complexes have been found to degrade in solutions exposed to ultraviolet light, but the photochemical effect on the solid species is unknown. As the concentration of free cyanide decreases below the concentration of metal cyanide complexes, the slower rate of decomposition of metal cyanide complexes becomes the rate controlling step for the volatilization of free cyanide. Other compounds that may be very sparingly soluble in water are iron, nickel, cobalt, and copper salts of iron complex cyanide ions. Until the presence of these complexes and compounds is exhausted, very small amounts of free cyanide may be released in the spent heap pile.

Besides volatilization directly from the mining wastes, a secondary transport process is the leaching of cyanide and any soluble metal cyanide complexes from the mining wastes and their transport into the environment if uncontained. Also possible would be the accidental release of cyanide process solution through pond overflows and pad or pond leaks (refer to Appendix D for reported accidents at heap leach mining operations). Volatilization is an important process for removing cyanide from surface water whereas other processes (biodegradation, reaction of cyanide to ammonia and formate, sorption, complexation, and others) may be more important for soil and ground water. The discussion of the mobility of cyanide in surface water, ground water, and soils is contained in the final part of the section, Environmental Fate of Cyanide.

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APPENDIX C

POTENTIAL EFFECTS OF CYANIDE

Cyanide in various forms can adversely affect living organisms. Free cyanide (CN-) and hydrogen cyanide (HCN) are readily absorbed and combine with certain enzymes in living tissue. Cyanide predominately affects respiration by inhibiting cytochrome oxidase, an enzyme required for oxidative metabolism.

Hydrogen cyanide is lethal to fish at water concentrations of 25 ug/l, but effects on reproduction have been observed at levels as low as 5.2 ug/l. Water temperature and the presence of light affect the toxicity of cyanide to aquatic organisms.

Loss of vegetation can result from cyanide spills, while sublethal concentrations can affect photosynthesis. Plant growth can be inhibited by cyanide in the presence of iron, but seed germination can be increased by sodium cyanide. Concentrations of HCN greater than 5 mg/l in irrigation water have been found to adversely affect some vegetation.

Cyanide can enter the bloodstream of birds and mammals (including humans) after inhalation, ingestion or cutaneous absorption. Toxicities of ingested hydrogen cyanide are reported at 3 mg/kg body weight for mice, at 0.1 mg/kg body weight for birds, and at about 1 to 3 mg/kg body weight for humans. Inhalation of 100 to 300 mg/l HCN is fatal to most mammals, including humans. The human lethal dose for skin absorption is about 100 mg/kg body weight. Sublethal doses are detoxified and eliminated from the body. However, the detoxification process may inhibit iodine uptake, causing goiters.

Toxicity of cyanide to various organisms is discussed in greater detail below. For a discussion on the behavior of cyanide in the environment, see Appendix B.

TOXICITY OF CYANIDE TO AQUATIC ORGANISMS

Introduction

Cyanide can be introduced into aquatic organisms by absorption through the skin or the gills and is readily transported throughout the body by general circulation. Of the many forms of cyanide, free cyanide is the most toxic to aquatic organisms. Between pH 6.8 and 8.3 the molecular species, hydrogen cyanide (HCN), is more toxic than the ionized species, cyanide ion (CN^-). Molecular hydrogen cyanide diffuses through semi-permeable membranes more readily than the cyanide ion, but once inside, the ionic form becomes the reactive agent because of its unpaired electron (Huiatt et al., 1983; Heming and Thurston, 1984). Above pH 8.3, CN^- also readily penetrates these membranes. The unpaired electron produces a strong nucleophilic center and therefore reacts with many transition metals and sulfhydryl groups.

Metalloporphyrins and molecules with a disulfide bond are the most important biological molecules affected by HCN. Metalloporphyrins which are sensitive to cyanide inhibition include cytochrome oxidase, catalases, and peroxidases. Cyanide inhibits oxidative phosphorylation causing cytotoxic anoxia. Death results from depression of the central nervous system which is the most sensitive tissue to anoxia. The effect of cyanide to catalase and cytochrome oxidase is reversible. Cyanide irreversibly affects sulfur-containing enzymes involved in respiration (Huiatt et al., 1983). Succinate dehydrogenase is an iron-sulfur protein which passes electrons to the cytochrome system and is inhibited by cyanide.

Cyanide is detoxified primarily by the enzyme rhodanese which forms the less toxic thiocyanate ion. However, thiocyanate interferes with the incorporation of iodide by the thyroid gland. A continuous intake of HCN without sufficient iodine in the diet to overcome its effect causes goiter. Thiocyanate also inhibits transport of halides in the stomach, cornea, and gills, and inhibits other enzymes (Heming and Thurston, 1984).

The toxicity of metallocyanide complexes depends on the degree to which they dissociate to release free cyanide. Zinc cyanide and cadmium cyanide complexes readily dissociate in aqueous solutions and are highly toxic. Copper cyanide, nickel cyanide, and silver cyanide dissociate to a moderate degree while iron cyanide and cobalt cyanide are tightly bound and considered nontoxic (Heming and Thurston, 1984). However, ferrocyanide and ferricyanide, which may be byproducts of the cyanidation process used to extract gold from ore, may photodecompose and become much more toxic (Burdick and Lipshuetz, 1950; Heming and Thurston, 1984).

Free cyanide is a much more reliable index of toxicity than total cyanide because total cyanide can include organic cyanides and metallocyanide complexes (U.S. Environmental Protection Agency, 1985). Measurement of free cyanide should be adequate for monitoring purposes if performed often over a wide area. However, if only a few measurements are made on a water body or if an effluent is measured, free cyanide at the lowest pH occurring in the receiving water, cyanide amenable to chlorination, or total cyanide may be more appropriate (U.S. Environmental Protection Agency, 1985) (see Appendix B for a more complete discussion). If total cyanide is much higher than free cyanide or cyanide amenable to chlorination, the importance of free cyanide released from metallocyanide complexes should be considered. Also, dilution of an effluent with receiving water before measuring cyanide should demonstrate whether the receiving water can decrease the cyanide of concern because of sorption or complexation.

Acute Toxicity of Cyanide

Concentrations of hydrogen cyanide lethal to fish range from about 25 ug/l to about 300 ug/l whereas invertebrates are typically much more tolerant (Table C-1). Salmonids, especially rainbow trout (Salmo gairdneri) are the most sensitive fish species. Embryos and sac fry tend to be more tolerant than juveniles and adults.

Table C-1
Toxicity of Cyanide (HCN) to Aquatic Animals

Species	96-h LC50 (ug/l)	HATC ^a / (ug/l)	Concentrations with Effects (ug/l)	Remarks	Authors
<u>Salvelinus fontinalis</u> (juvenile)	75; 6.9 °C				
(juvenile)	88; 10 °C				
(juvenile)	98; 13 °C				
(swim-up fry)	55-104				Smith et al., 1978
<u>Pimephales promelas</u> (juvenile)	121; 15 °C				
	137; 20 °C				
	129; 25 °C				
<u>Lepomis macrochirus</u>	83; 8.4 °C				
	87; 15.0 °C				
	120; 24.9 °C				
<u>Perca flavescens</u>	90; 15 °C				
	102; 21 °C				
<u>Salmo gairdneri</u> (juvenile)	28; 6 °C				Kovacs and Leduc, 1982
	42; 12 °C				
	68; 10 °C				
<u>Salmo salar</u>	73; D.O. b/				
	10 mg/l (24 hr)				
	24; D.O. = 3.5				
	mg/l (24 hr)				Alabaster et al., 1983
<u>Pimephales promelas</u>	114 (192 hr)				
<u>Lepomis macrochirus</u>	116 (168 hr)				
<u>Salvelinus fontinalis</u>	126 (288 hr)				
<u>Carassius auratus</u>	261 (336 hr)				Cardwell et al., 1976
<u>Anellus communis</u>	2295	41, c/ 55d/		Reduced numbers and weight. <u>Gammarus</u> was affected by presence of <u>Anellus</u> .	Oneid and Smith, 1979
<u>Gammarus pseudolimnium</u>	169	16 ^c /, 21 ^d / 4, e/ 9f/			
<u>Pteonarcys dorsata</u>	426				U.S. EPA, 1985
<u>Tanytarsus dissimilis</u>	2490				U.S. EPA, 1985
<u>Pimephales promelas</u>			19.6	Egg production reduced.	Lind et al., 1977

(continued)

Table C-1 (Continued)

Species	96-h LC50 (ug/l)	Concentrations with MTC ^a / Effects (ug/l)	Remarks	Authors
<u>Lepomis macrochirus</u>				
		5 (to protect com- plete life history)	60% survival 40% survival Spawning inhibited	Kimball et al., 1978
		50 (without reproduction 15.6-19.4 or fry life 54.0 stages); 25°C	Behavioral changes after 289 days Fry survival affected Juvenile survival affected	
<u>Jordanella floridae</u>				
		75.0	Reduced hatching success to 37%; egg production of exposed embryos reduced by 33%.	Cheng and Ruby, 1981
		65.0 (5 days)	Embryonic, juvenile exposure caused 40% reduction in egg production; 33% reduction in hatching of F1	
		65.0	30% of treated embryos had eye defects.	
		75-87.0	40% of treated embryos had eye defects.	
		65.0	Delayed sexual maturity and shortened estrous cycle.	
<u>Salmo gairdneri</u>		10.0	Increased food maintenance requirements by 2-3 times of 18-g, but not 8-g fish. Growth rate of 18-g fish reduced 98%; of 8-g fish by 60%.	McCracken and Leduc, 1978
<u>Salmo gairdneri</u>		10.0 (18 days)	Reduced spermatogonia by 13%.	Ruby et al., 1979
		30.0 (18 days)	Reduced spermatogonia by 50%.	
<u>Salmo gairdneri, juv.</u>		20.0 (18 days)	40% growth reduction.	Dixon and Leduc, 1981.
		30.0 (18 days)	95% growth reduction and degenerative necrosis of hepatocytes.	
<u>Salmo gairdneri</u>		10.0 (20 days, 10°C during late egg development)	Altered patterns of secondary yolk deposition.	Lesniak and Ruby, 1982.
		20.0 (20 days, 10°C during early summer)	Secondary yolk deposition delayed.	
		10.0 (20 days in mid- summer)	60% of oocytes failed to reach secondary yolk deposition.	
<u>Salmo salar</u>	5.0	80-100, continuously 10.0	Delayed hatching by 6-9 days. Reduced hatching success. Conversion of yolk into body tissue reduced.	Leduc, 1978.

(continued)

Table C-1 (Continued)

Species	Concentrations			Remarks	Authors
	96-h LC50 (ug/l)	MATC ^{a/} (ug/l)	with Effects (ug/l)		
<u>Salvelinus fontinalis</u>		5.7-11.2	34.0 11.2 53.9 64.9	Growth was affected. Egg production was reduced. Egg viability was reduced. No viable eggs were produced.	Koenst et al., 1977.

a/ MATC = Maximum acceptable toxicant concentration.

b/ D.O. = Dissolved oxygen.

c/ Based on total number of eggs or young in brood pouch.

d/ Based on number of eggs per gravid female.

e/ Based on total number of eggs or young in brood pouch and competition with Asellus.

f/ Based on number of eggs per gravid female and competition with Asellus.

Temperature is an important factor in the toxicity of hydrogen cyanide. Toxicity of HCN to fish generally increases with decreasing temperature (Smith et al., 1979; Kovacs and Leduc, 1982) (Table C-1). At slowly-lethal concentrations (greater than 100 ug/l HCN), HCN was more toxic at lower temperatures, but at rapidly-lethal concentrations, HCN was more toxic at higher temperatures. Kovacs and Leduc (1982) also found that warm-acclimated trout survived longer in lethal concentrations of HCN.

Lethal threshold concentrations were reduced 20 to 30 percent when oxygen concentration was reduced by 50 percent (Smith et al., 1979). Brook trout (Salvelinus fontinalis) alevins with yolk sacs exhibited a 500 percent decrease in lethal threshold concentrations, while alevins which had absorbed their yolk sacs became 200 percent more sensitive. Alabaster et al. (1983) reported a decrease of 67 percent in the LC50 (lethal concentration to 50 percent of the organisms) when dissolved oxygen declined from 10 mg/l to 3.5 mg/l.

There is little information which addresses the affect of hardness on the toxicity of HCN. In general, hardness of water appears to have no significant affect on the toxicity of hydrogen cyanide (Huiatt et al., 1983).

Because the iron cyanide complexes photodecompose, light has an effect on toxicity of these cyanide complexes. Burdick and Lipschuetz (1950) found that potassium ferrocyanide or ferricyanide in concentrations of 2000 ug/l rapidly became toxic in the presence of light. Increasing the intensity of light also increased the toxicity of ferrocyanide and ferricyanide (Heming and Thurston, 1984). However, unless receiving waters are clear and shallow, photolysis of the iron-cyanide complexes is probably not nearly as rapid as that observed in laboratory tests. Free cyanide produced by photolysis may react and complex again or escape to the atmosphere as quickly as it is released. Lethal concentrations of cyanide may not be often attained even in waters receiving large amounts of iron-cyanide complexes (Doudoroff, 1976).

Pre-exposure to high sublethal levels (50 ug/l) of hydrogen cyanide can cause a reduced tolerance to lethal concentrations of hydrogen cyanide. Dixon and Sprague (1981) exposed rainbow trout to 0.35 of the incipient lethal level of cyanide for 1 and 2 weeks. Tolerance to cyanide decreased by 32 and 15 percent, respectively. Following this initial sensitization, tolerance returned to that of control fish after 21 days. Pre-exposure to low sublethal levels (10 ug/l) can increase resistance to a lethal concentration (Douderoff, 1976).

The effect of cyanide appears to be related to the metabolism and therefore the size of fish. Anderson and Weber (1975) found the LC50 of HCN for guppies (Poecilia reticulata) depended on weight and was described by $0.147W^{0.72}$, where W is the weight in grams of a group of 10 fish of a given size class. Less toxicant was required to kill one gram of heavy fish than one gram of light fish (Anderson and Weber, 1975). McCracken and Leduc (1978) also reported HCN affected large rainbow trout more strongly than small trout. Since cyanide is a respiratory depressant, an increase in size causes an unproportional cost of ventilation because large fish have a proportionally smaller gill area. The authors proposed that cyanide could act as a regulator of the basal metabolic rate.

Chronic Toxicity of Cyanide

Reproduction

Cyanide affects spawning, egg production, egg development, and production of spermatogonia (Table C-1). Spawning of bluegill sunfish (Leponis macrochirus) was inhibited at 5.2 ug/l HCN (Kimball et al., 1978). Egg production per female brook trout was reduced by 50 percent following a 144-day exposure to 27 ug/l HCN at 9 to 15° C (48 to 59° F) (Koenst et al., 1977). Egg production per female fathead minnow (Pimephales promelas) was reduced by 50 percent at an HCN concentration of approximately 15 ug/l. Cheng and Ruby (1981) followed the effects of cyanide through the F1 (second) generation of American flagfish (Jordanelia floridae), and found juvenile ovaries were highly sensitive

to HCN. A 5-day exposure of embryos and juveniles to 65 ug/l HCN produced a 40 percent reduction in egg production at sexual maturity and a further 33 percent reduction in the hatching success of the F1 generation. Embryonic exposure alone to 75 ug/l HCN reduced by 30 percent the fecundity of the embryos which matured. Exposure during embryonic development also appeared responsible for a shortened estrous cycle and delayed sexual maturity.

The development of oocytes and spermatogonia of rainbow trout is seriously affected by cyanide (Table C-1). Lesniak and Ruby (1982) found that yolk deposition was delayed or failed following exposure to HCN at 10 to 20 ug/l for periods of 15 to 20 days during early, mid, and late development periods. Following exposure to 10 and 30 ug/l HCN, 13 and 50 percent, respectively, of dividing spermatogonia in juvenile trout failed to complete mitosis (Ruby et al., 1979).

Early Life Stages

As described in the previous section, hatching success can be adversely affected by exposure to cyanide of the developing oocytes before they are fertilized. Although Smith et al. (1979) described the egg as the most tolerant stage, hatching success of Atlantic salmon (*Salmo salar*) eggs was reduced by 15 to 40 percent when incubated in HCN concentrations of 80 to 100 ug/l (Leduc, 1978). During incubation, conversion of yolk into body tissues was reduced at concentrations above 10 ug/l HCN. The authors stated that sensitivity of the egg begins when morphogenesis becomes aerobic after blastulation. Observed teratogenic anomalies seemed to arise from this sensitivity of aerobic processes during embryogenesis. Survival of sac fry and larvae was not adversely affected by HCN. At intermediate concentrations, fry grew faster than controls because yolk conversion efficiency ratios were higher, especially at 40 ug/l HCN or more.

Kimball et al. (1978) also reported a significant reduction in survival of blue gill sunfish eggs at 38.6 ug/l HCN. Fry survival was also adversely affected at 15.6 to 19.4 ug/l HCN, but juveniles were

not affected by concentrations below 53.1 ug/l at 25° C (77° F). Eye defects were observed in 30 percent of American flagfish embryos exposed to 65 ug/l HCN and in 40 percent of embryos exposed to 75 ug/l HCN (Cheng and Ruby, 1981).

Juvenile and Adult Life Stages

As discussed previously, the juvenile ovary is highly sensitive to cyanide. The growth response of juvenile fish to HCN is variable. Dixon and Leduc (1981) observed that growth was reduced by 40 to 95 percent following 18 days of exposure to 20 and 30 ug/l HCN, respectively. This severe initial repression of the specific growth rate was followed by a highly significant growth increase which was insufficient to compensate for the initial repression. Wide-spread degenerative necrosis of the hepatocytes was discovered at 10 ug/l HCN although no other poisoning symptoms appeared. Growth enhancements may also occur at low concentrations (about 10 ug/l HCN) when the metabolic rate of fish is stimulated (McCracken and Leduc, 1978; Kovacs and Leduc, 1982). McCracken and Leduc (1978) described cyanide-induced lipogenesis in small rainbow trout (8 grams) but a depletion in fat reserves in large trout (18 grams). Cyanide increased food maintenance requirements of 18-gram rainbow trout by 2 to 3 times over controls, but it had no effects on 8-gram trout at 10 ug/l. Cyanide caused growth to be proportional to body surface rather than weight so large fish were severely affected while growth in small fish was enhanced.

The survival of bluegill sunfish was not markedly affected by cyanide at sublethal concentrations until spawning started. Death occurred after a series of behavioral changes which included a lack of feeding activity and aggressiveness; impairment of the ability to judge distance and capture prey; and gradual changes in swimming behavior. The time from the first observation of these symptoms to death was two weeks. Early stages were noticeable at 50.2 ug/l HCN after 289 days. Survival was 60 percent at 65.6 ug/l HCN and 40 percent at 80.0 ug/l.

Invertebrates

When the aggressive and competitive amphipod Gammarus pseudolimn-
nus was exposed to hydrogen cyanide, the competitive advantage shifted
to the isopod Asellus communis which is more tolerant of cyanide (Oseid
and Smith, 1979) (Table C-1). Asellus was able to reproduce at HCN
concentrations up to 317 ug/l after a continuous exposure of 115 days.
Gammarus required much lower cyanide concentrations to reproduce.

Cyanide Concentrations Which Protect Aquatic Life

Koenst et al. (1977), Leduc (1978), and Kimball et al. (1978)
determined that the maximum acceptable tolerance concentration, or
no-effect concentration, is 5 to 10 ug/l HCN for fish, which is similar
to that determined for Gammarus pseudolimninus (Table C-1). Other
invertebrates can tolerate much higher concentrations. If reproduction
and early life stages of bluegill sunfish are not considered, 50 ug/l
HCN can be tolerated at higher temperatures (25° C or 77° F).

The EPA determined that freshwater organisms and their uses should
not be unacceptably affected if free cyanide does not exceed 5.2 ug/l
more than once every three years on the average and if the 1 hour
average does not exceed 22 ug/l more than once every three years on the
average. These criteria may be overly protective when measuring
cyanide as total cyanide.

EFFECTS OF CYANIDE ON VEGETATION, LIVESTOCK AND WILDLIFE

Introduction

Cyanide is a highly reactive molecule. In the environment free
cyanide will react with various forms of sulfur to form thiocyanate,
complex with trace metals, be metabolized by microorganisms, oxidize to
cyanate and degrade chemically to carbon dioxide and ammonia, react
with organic matter and/or react to ammonia and formate (Huiatt, et al.
1983). The soil factors most responsible for attenuation of cyanide in
the environment are clay content, depth of soil, hydrous oxides of
various metals, aerobic conditions and concentration of soil organic
matter (Fuller, 1985).

No evidence of bioaccumulation of complexed cyanides within organisms or food chains is reported in the technical literature. Studies have shown that cyanide is readily metabolized and/or converted to non- or less toxic forms by several species of microorganisms, plants, and animals.

Cyanide compounds occur naturally in the majority of plant species studied. The main group of cyanide compounds in plants is the cyanogenic glycosides. These compounds have been identified in approximately 1,000 plant species (Towill et al., 1978). Plants such as sorghum and arrow-grass (*Triglochin* spp.) can develop concentrations of cyanogenic glycosides which release enough cyanide to poison cattle and sheep (Towill et al., 1978). When livestock consume such plants, cyanogenic glycosides are hydrolyzed, releasing hydrogen cyanide.

Effects on Vegetation

Plants are able to metabolize sublethal concentrations of externally-added hydrogen cyanide. Toxic concentrations of cyanide to plants can occur in the event of a cyanide release if the soil microbial degradation rate and natural soil ¹ating capacities of the soil are exceeded (Fuller, 1985). To ¹ of cyanide may result in the loss of vegetation in the immediate vicinity (Stanton et al., 1985).

There is little published information on concentrations of cyanide in soils which may be toxic to plants. Dandelion in a 5,000 mg/l solution of sodium cyanide developed numerous dead leaves after 48 hours (Howe and Noble, 1983). Alfalfa responses to cyanide in irrigation water was found to be depressed at greater than 5 mg/l of hydrogen cyanide (Overcash and Pal, 1979).

The toxic effect of cyanide in plants is due primarily to inhibition of various enzymes (Towill et al., 1978). Cytochrome oxidase, the terminal electron acceptor in the electron transport chain, is probably the most sensitive enzyme. Plant respiration is affected by inhibition of cytochrome oxidase. Cyanide can react with metals in other enzymes such as uricase, nitrate reductase, tyrosinase, and carboxypeptidase, thus rendering these enzymes ineffective.

Cyanide can adversely affect photosynthesis by removal of copper from plastocyanin (Towill et al., 1978). Evidence suggests that plant growth can be inhibited by cyanide, especially in the presence of iron. Conversely, seed germination can be stimulated by soaking in a solution of sodium cyanide (Towill et al., 1978).

Effects on Livestock and Wildlife

Considerable research has been conducted on the effects of cyanide on aquatic organisms (refer to the previous section on toxicity of cyanide to aquatic organisms). Information about the effects of cyanide on terrestrial wildlife is not as complete (Stanton et al., 1985).

Free cyanide and its alkali metal salts have a high inherent lethality to man and other mammals (Huiatt et al., 1983). Lethal threshold concentrations vary among species tested. The concentration reported to be toxic to mice is 3 mg/kg while that for birds is about 0.1 mg/kg. Airborne HCN levels greater than 200 ppm are regarded as lethal to mammals while levels of 80 to 160 ppm may cause sublethal toxic effects (Feigley et al., 1985). As in plants, the main inhibitory effect of cyanide in mammals is on respiration.

Research with dogs indicates that large (0.5 to 2.0 mg/kg) but sublethal doses of cyanide administered periodically may be tolerated. Rats fed diets containing as much as 300 ppm cyanide for up to three years showed little chronic effects (Feigley et al., 1985). Other researchers observed neither death nor clinical signs of toxicity in rats fed diets containing 1,500 ppm potassium cyanide or 2,240 ppm potassium thiocyanate for nearly 1 year (Feigley et al., 1985). There

is currently no evidence that chronic exposure to cyanide results in teratogenic (changes produced in offspring), mutagenic or carcinogenic effects. However, extensive evidence exists to support the contention that long-term adverse effects can occur to humans and other animals which consume cyanide-containing food and medicine (Stanton et al., 1985).

An operating heap leach operation may contain a solution concentration of about 500 mg/l of sodium cyanide (equivalent to about 250 mg/l free cyanide) (Stanton et al., 1985). A properly operating facility where access is controlled, should pose little threat to livestock and wildlife. Releases of cyanide would be more likely to affect aquatic life although some poisoning of animals drinking process solution could occur. Cyanide emissions from heap leaching would have to be greater than 80 mg/l to potentially affect rodent populations (Feigley et al., 1985).

In documented cases of acute cyanide poisoning, the affected animal becomes severely distressed and either dies or rapidly recovers. Due to cyanide's high biological reactivity and plant and mammalian detoxification mechanisms, cyanide is not accumulated or stored in any mammalian species studied (Hufatt et al., 1983).

HUMAN HEALTH EFFECTS OF CYANIDE

The toxicological effects of cyanides on humans are based on their potential for rapid conversion to hydrogen cyanide (HCN). Cyanide can be absorbed into the bloodstream after inhalation, ingestion, or cutaneous adsorption. In the bloodstream, cyanide binds to metal constituents of certain enzymes, the most sensitive of which is cytochrome oxidase. The cyanide ion reacts with the trivalent iron present in the cytochrome oxidase, inactivating the enzyme, thereby preventing oxygen utilization by the cells. The central nervous system is particularly dependent on oxidative metabolism, the absence of which causes cytotoxic anoxia, with death resulting from depression of the central nervous system. In sublethal doses, cyanide is converted by cells to less toxic forms. The primary detoxification pathway is the reaction

of cyanide with thiosulfate in the presence of the enzyme rhodanese, to produce thiocyanate. Thiocyanate is eliminated in the urine. There is a low degree of chronic toxicity because cyanide is either lethal or detoxified. It does not bioaccumulate in the body, and there is no evidence that cyanide is mutagenic, teratogenic, or carcinogenic. However, Hamilton and Hardy (1974) have implicated a degradation product of cyanide, i.e. thiocyanate, in the development of goiters in animals. They suggest the thiocyanate radical, by preventing iodine uptake, may be responsible for the effect. It has been suggested that continued exposure to cyanide in industry, even at low levels, can produce thiocyanate changes in the thyroid gland.

Hydrogen cyanide vapor is rapidly absorbed through the lungs. Inhalation of 100 to 300 mg/l HCN vapor is fatal (Huiatt et al., 1983). Tobacco smoke is a common source of low concentration HCN, which is converted to thiocyanate by the body and excreted. Inhalation of cyanide salt dusts can also be absorbed into the bloodstream since the cyanide will dissolve on contact with moist mucous membranes of the lungs.

The mean lethal dose of cyanide substances ingested by mouth in human adults is in the range of 50 to 200 milligrams (Huiatt et al., 1983). The EPA (1985) recommends an ambient water quality concentration not to exceed 0.2 mg/l free cyanide which would be protective of human health against ingestion of contaminated water and fish found in contaminated water. No human cases of illness or death from cyanide in water supplies are known although some waste cyanide is still being discharged from such industries as steel and electroplating, mining operations, and hospital laboratories.

Hydrogen cyanide can also be absorbed through the skin particularly if the skin is cut, abraded, or moist. There is one reported case (Potter, 1950) in which liquid HCN ran over the bare hand of a worker wearing a respirator. The worker collapsed into deep unconsciousness within five minutes. The lethal dose (LD50) for skin absorption is about 100 mg/kg body weight (Huiatt et al., 1983).

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APPENDIX D
CYANIDE SPILLS AND RESULTING
ENVIRONMENTAL ATTENUATION FACTORS

ACCIDENTS FROM HEAP LEACHING PRACTICES IN THE WESTERN UNITED STATES
AND THEIR IMPACTS

The accidental spill record for heap leach operations in the western United States indicates that several accidents having detrimental impacts have occurred. By far the most common type of problem has been with ponds overflowing during periods of high runoff. The other types of accidents are usually related to either leaks in the pond liners or leaks in the heap pad liners. The incidents which have been reported to each state and their impacts, when they could be identified, are described below.

Arizona

There are several cyanide heap leach operations in Arizona. Under Arizona state law, state officials are not permitted to divulge information regarding accidents or spills which occur in the mining industry (J. McCutchan, Arizona State Mine Inspector, personal communication, 1986).

California

Mining operations in California are regulated by separate regional water quality divisions. Three regions have active cyanide heap leach activities. In Region 5, an accident occurred in the spring of 1986 at the Cal-Gon mine near Canyon Dam (B. Kroyle, California Regional Water Quality Board-Region 5, personal communication, 1986). Waters from the process ponds had to be released after a large snowstorm, combined with warm weather and rain storms, caused ponds to overflow. The site is located on 25 meters (80 feet) of impermeable clay so the operators were able to dig temporary ponds for storage of some of the excess water. However, 23,000 cubic meters (6 million gallons) of treated waters (5 to 20 mg/l free cyanide) had to be released at a rate of

0.0022 cubic meters per second (35 gallons per minute). The outflow point was located 6 meters (20 feet) from a tributary stream that was flowing at a rate of approximately 0.022 cubic meters per second (350 gallons per minute). Concentrations of free cyanide ranged from 20 to 30 mg/l in this tributary. The creek then flowed approximately 2.4 kilometers (1.5 miles) to Wolf Creek, which was flowing at approximately 60 cubic meters per second (2000 cfs). No cyanide was detected in Wolf Creek (detection limit 0.01 mg/l). The higher concentrations of cyanide in the tributary are believed to be a result of mismanaged tailings from past operations. Five ground water monitoring wells were installed. Samples from one well contained small amounts of cyanide. Chlorine was immediately added to the well to oxidize the cyanide. An extensive program of aquatic life sampling was conducted but no aquatic life problems were found.

In Region 6 there has been a slight problem with one of the heap leach double-synthetic pad liners constructed by Beaver Resources (M. Watkins, California Regional Water Quality Board - Region 6, personal communication, 1986). The liner was installed properly but heavy machinery was permitted to drive across the liner which tore and weakened it. The leak was localized and the leachate was contained in the leak detection system. There was no known contamination in either the ground water or surface water.

Leakage has also been reported from an inactive heap leach operation of the American Mine in the Mojave Desert also located in Region 6 (U.S. Environmental Protection Agency, 1986). Breaks in the PVC liners used below several inactive leach heaps allowed rainwater to percolate through the heaps and into the soil at 59 sample locations. Soil core samples were analyzed for free cyanide and it was found that the maximum penetration into the soil ranged from 46 to 61 centimeters (18 to 24 inches). Four heaps were analyzed. Two of the heaps, which had been idle for more than 2 years, contained no measurable cyanide while some samples from the other two heaps had free cyanide concentrations from 10 to 150 mg/l. Water and sediment samples were also collected in the barren and pregnant solution ponds below the inactive heaps and

from the soils adjacent to and below the ponds. Free cyanide was not detected in the water from the barren pond but the sediment from the pond contained up to 500 mg/l free cyanide. Liner failures below the barren, pregnant, and overflow ponds occurred, and free cyanide was detected in soil cores with free cyanide concentrations up to 300 mg/l. The maximum depth of free cyanide detection was 61 centimeters (24 inches).

One incident involving heap leach practices has been reported in Region 7 (R. Rodriguez, California Regional Water Quality Board - Region 7, personal communication, 1986). At the Piccho Gold Mine, operated by Can-Gold, Inc., ponded water on top of the heap leach pile breached a levee and flowed into a collection pond. Can-Gold is currently involved in subsurface investigations because cyanide was detected in two ground water monitoring wells. The mining company claims the cyanide is from previous gold mining activities which also used cyanide. The subsurface investigation are designed to determine the source of the cyanide.

Colorado

In the State of Colorado there have been several minor accidents associated with cyanide heap leaching (M. Loye, Colorado Mined Land Reclamation Division, personal communication, 1986). Several years ago four horses died after drinking water from an overflow pond at the Newport Minerals Site. It was never determined if the horses died from cyanide poisoning or from caustic soda which had precipitated in the pond.

The facility at the Ruby Heap Leach site was abandoned without being reclaimed. During abandonment, the carbon columns were drained and cyanide flowed around the ponds and into an adjacent ephemeral drainage. No fish kill was associated with the spill and the flow never reached the perennial stream.

In 1984, the Cameron Mine owned by Newport Minerals had a cyanide release after a large storm caused a pond to overflow. The berm failed on the overflow pond due to inadequate drainage control. The spill

flowed into the adjacent creek but there was no information on how much cyanide was released. The concentrations were probably low because of the large dilution by the stream.

The most recent accident occurred at Neglected Mine owned by Mine Development Company. The site was permitted as a vat leach but was operated as a heap leach. A leak was discovered in the liner and cyanide was released. There was some evidence of cyanide contamination in the soils.

Idaho

There have been several accidental spills related to heap leaching practices in the state of Idaho (I. Nautch, Idaho Water Quality Bureau, personal communication, 1986). Two spills are suspected at the Sunbeam Mine. The first spill was reported in 1981, three months after the pond overflow occurred. A followup investigation did not detect any cyanide problems. The second spill at Sunbeam occurred in the spring of 1982 when a pond overflowed again. There was evidence of surface water contamination and a notice of violation was issued by the State of Idaho.

An accident at the Yellowjacket mine occurred in the spring of 1983. The accident is believed to have been an overflow pond problem. The overflow occurred before the state inspection, so the amount of time between the accident and subsequent sampling is unknown. A total cyanide concentration of 0.29 mg/l was detected in the surface water. It is unknown if soil samples were taken at the site. There was also evidence of a punctured liner in either the barren or the pregnant pond, which may have resulted in a leak to ground water. Monitoring wells were installed after cleanup and samples from them contained no evidence of cyanide.

During 1983 and 1984, the Elk City operation had some leakage problems in the primary trench leading to the pregnant pond (J. Moeller, Idaho Department of Health and Welfare, personal communication, 1986). Samples indicated cyanide contamination of both the ground water and soil. Ground water analysis showed 9 to 10 mg/l total

cyanide, 1 mg/l weak acid dissociable (WAD) cyanide, and 1 mg/l free cyanide. Ground water was contaminated for 30 to 46 meters (100 to 150) feet beyond the problem area. Evidence of soil contamination from cyanide was found 0.3 meter (1 foot) below the surface. There are no reports on contamination of vegetation. High total cyanide (6 mg/l) was found in Elk Creek and the Elk City water supply just downstream. The leak area was located approximately 120 meters (400 feet) from the creek. Cleanup costs are estimated at \$500,000.

The most recent spill occurred in the spring of 1986 at the Comeback Mine when a process pond containing a concentration of 200 mg/l WAD and free cyanide overflowed. The discharge flowed over snow and ice covered land for approximately 1 kilometer (0.5 mile) before it reached the stream, where less than 1 mg/l of free cyanide was detected. There was no evidence of ground water or soil contamination.

New Mexico

In the summer of 1984, the catchment pond and dam located below the waste residue pile of the Gold Field Mine overflowed because of heavy rains (A. Die, New Mexico Environmental Improvement Division, personal communication, 1986). Total cyanide concentrations of 0.5 to 0.6 mg/l were detected in several monitoring wells. The pregnant pond came within several inches of overtopping. No other impacts were observed.

Montana

The Golden Maple Mine in Gilt Edge is the only mining operation which has had a problem associated with heap leaching practices in Montana (D. Smith, Montana Department of State Lands, personal communication, 1986). During the spring of 1985, the ponds were close to breaching, so the operation released pond water to prevent destruction of their dike. The released water contained concentrations of 35 mg/l total cyanide and 27 mg/l chlorine amenable cyanide. The released pond water flowed down a dry streambed and infiltrated the alluvium. Cyanide was detected in a ground water monitoring well located within the mine permit area and in a ranch well approximately 0.4 kilometer

(0.25 mile) away. The highest cyanide concentration measured from samples from the rancher's well was 0.199 mg/l total cyanide and 0.14 mg/l chlorine amenable cyanide in November 1985. The cyanide has since dissipated. The ground water from the bedrock aquifer was also sampled but no cyanide was detected.

Nevada

One accident has been associated with cyanide heap leach operations in Nevada (H. Van Drieun, Nevada Division of Environmental Protection, personal communication, 1986). Nevex Mining Company had an operation where the heap leach operations were unfenced. Four cows and a bull died instantly after drinking the cyanide solution from one of the process ponds.

Oregon

In Oregon, a heap leach operation was recently abandoned because the operator had problems with the cyanide process (K. Ashbaker, Oregon Department of Environmental Quality, personal communication, 1986). The cyanide solution would not penetrate the ore but continually ran off the pile. No cyanide has been detected in the ground water or the surface water.

South Dakota

In May 1984, there was a spill at Wharf Resources at the Annie Creek mine caused by high rainfall and snowmelt (B. Townsend, South Dakota Department of Natural Resources, personal communication, 1986). The upper pregnant and barren ponds overflowed into the overflow pond which was only clay lined. The released water contained a concentration of approximately 100 mg/l total cyanide. The clay liner contained concentrations of approximately 2 to 3 mg/l total cyanide, with a maximum concentration of 14 mg/l cyanide. At about the same time, a tear was discovered in the barren pond Hypalon liner. Cyanide solution seeped into the clay liner below. The tear was repaired and the contaminated clay was removed.

Utah

There have not been any problems with the small cyanide operations in the last 6 years in Utah (C. Dietz, Utah Water Pollution Control Division, personal communication, 1986). However, there is one large operation, the Mercur Mine, which has had a problem with their heap leach pads. The liner under the heap leach pile was constructed with a sand blanket, geotextile, clay and synthetic liners. The leak detection system detected 6×10^{-5} to 1×10^{-4} cubic meters per second (1 to 2 gallons per minute) of leach solution containing up to 120 to 130 mg/l free cyanide. The spraying solution was applied at a rate of 0.01 cubic meters per second (200 gallons per minute). No impacts occurred because the leak was contained in the leak detection system. Mercur's second leach pile liner also leaked into the leak detection system. There are no ground water monitoring wells because the bedrock is highly fractured. Direction of plume movement is, therefore, difficult to ascertain.

Washington

There have been no cyanide heap leach operations in Washington. One operation will be permitted by the beginning of 1987 (B. Lingky, Washington Department of Natural Resources, personal communication, 1986).

Wyoming

The State of Wyoming has no major cyanide heap leach operations (C. Bosco, Wyoming Land Quality Division, personal communication, 1986). There are some small operations which have not reported any problems.

SELECTION OF A CYANIDE ATTENUATION FACTOR FOR CHAPTER 4

The accidental spill of process solution at the hypothetical mining operation discussed in Chapter 4 occurred during the springtime as a result of snowmelt combined with a heavy thunderstorm. The process solution from the pond flowed across the saturated ground, which was partially snow covered for approximately 1 kilometer (0.5

mile), and entered a small tributary, which flows about 3 kilometers (2 miles) until it joins a main drainage. Several mining operations have had similar incidents but usually inadequate data are reported to be able to calculate the attenuation of cyanide. The only reported accident having sufficient data was that at the Comeback operation in Idaho.

At Comeback a release of process solution, with concentrations of 200 mg/l weak acid dissociable and free cyanide, flowed over the snow- and ice-covered ground surface for approximately 1 kilometer (0.5 mile) before it reached a stream (I. Nautch, Idaho Water Quality Bureau, personal communication, 1986). The flow which entered the stream contained concentrations of less than 1 mg/l of free cyanide. The attenuation of cyanide as a result of flowing over the ground for approximately 1 kilometer (0.5 mile) was two orders of magnitude.

Based on Broderius's (1977) research on water from different sources spiked with cyanide ranging from 25 to 200 ug/l, the half-life for volatilization of HCN is from 0.37 to 2.3 days. Simovic et al. (1985) found the cyanide concentration of an aerated solution (pH 7 and 4° C) initially at 200 mg/l was reduced to less than 1 mg/l after about 230 hours (9.6 days). The decay rate was much higher during the first 80 hours (2.1 mg/l per hour). Assuming a stream velocity of 0.3 meter per second (1 foot per second) for the accidental spill discussed above, the spill would take approximately 3 hours to reach the mouth of the 3 kilometer- (2-mile) long tributary. Using the range from Broderius, it would take from 6 hours to 4 days more to reduce the free cyanide content by half after the spill reached the main drainage.

For the accidental spill described in Chapter 4, an attenuation factor of 2 orders of magnitude is used as the spill flows over the ground, based on the data from Comeback mine. Since there is no actual data on the attenuation of cyanide in streams and because experimental data show volatilization to be a relatively slow process compared to the stream flow rate, only dilution will be used to decrease cyanide in streams. Using only dilution factors to reduce cyanide concentration

in streams is conservative; in actuality, processes such as volatilization, reaction of cyanide to ammonia and formate, oxidation, metal complexation, biodegradation, sorption, and formation of simple and complex compounds should reduce the free cyanide concentration considerably.

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